DOCUMENT RESUME

ED 095 873 IR 001 055

AUTHOR	Dick, Robert A.; And Others
TITLE	Personnel Technology: Using an Inexpensive Computer-Based System to Teach Performance-Oriented Skill. Technical Report No. 1728-1. Final Report.
INSTITUTION	Human Factors Research, Inc., Goleta, Calif.
SPONS AGENCY	Office of Naval Research, Washington, D.C. Personnel and Training Research Programs Office.
REPORT NO	HFR-TR-1728-1
PUB DATE	1 Jun 74
NOTE	166p.; March 27, 1972--December 31, 1973 (Report period)
EDRS PRICE	MF-$0.75 HC-$7.80 PLUS POSTAGE
DESCRIPTORS	*Computer Assisted Instruction; *Computer Science Education; Electronic Technicians; Performance Based Education; *Programed Instruction; *Programed Texts; *Simulation

ABSTRACT

This research program compared computer-based and programed textbook-based curricula for training students to troubleshoot digital logic circuits. Students were matched in pairs on two pretests, a verbal aptitude test, and an electronics and mathematics aptitude test, and randomly assigned to the two curricula, which contained identical theoretical material. The two training programs differed principally in that the computer-based curriculum provided simulation of trouble-shooting experience through interaction with the computer, while the programed textbook-based curriculum had to rely solely on written explanations. Two criterion measures were employed, a written multiple-choice test of theoretical knowledge and an actual trouble-shooting session on faulty digital logic circuits. These were applied within a week and repeated 9 weeks after completion of the course. While observation and anecdotal evidence suggested that the computer-based curriculum was more interesting and stimulating, expecially for the brighter students, none of the objective measures showed an advantage for the computer group. (Author/WH)

A1

ED 095873

TECHNICAL REPORT 1728-1
THIS RESEARCH WAS FUNDED BY
THE OFFICE OF NAVAL RESEARCH,
PERSONNEL AND TRAINING RESEARCH PROGRAMS,
PSYCHOLOGICAL SCIENCES DIVISION, UNDER
CONTRACT NO. N00014-72-C-0370
NR154-348
JUNE 1974

SCOPE OF INTEREST NOTICE

The ERIC Facility has assigned this document for processing to: IR

CE

In our judgement, this document is also of interest to the clearinghouses noted to the right. Indexing should reflect their special points of view.

PERSONNEL TECHNOLOGY: USING AN INEXPENSIVE COMPUTER-BASED SYSTEM TO TEACH PERFORMANCE-ORIENTED SKILL

(FINAL REPORT)

ROBERT A. DICK
JACKSON W. ROYAL
HENRY K. SIMPSON
ROBERT R. MACKIE

U.S. DEPARTMENT OF HEALTH,
EDUCATION & WELFARE
NATIONAL INSTITUTE OF
EDUCATION
THIS DOCUMENT HAS BEEN REPRODUCED EXACTLY AS RECEIVED FROM THE PERSON OR ORGANIZATION ORIGINATING IT. POINTS OF VIEW OR OPINIONS STATED DO NOT NECESSARILY REPRESENT OFFICIAL NATIONAL INSTITUTE OF EDUCATION POSITION OR POLICY

IR 001 035

THIS DOCUMENT HAS BEEN APPROVED FOR PUBLIC RELEASE; ITS DISTRIBUTION IS UNLIMITED

HUMAN FACTORS RESEARCH, INCORPORATED
SANTA BARBARA RESEARCH PARK, GOLETA, CALIFORNIA

UNCLASSIFIED

BEST COPY AVAILABLE

SECURITY CLASSIFICATION OF THIS PAGE *(When Data Entered)*

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
Technical Report 1728-1

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE *(and Subtitle)*
Personnel Technology: Using an Inexpensive Computer-Based System to Teach Performance-Oriented Skill

5. TYPE OF REPORT & PERIOD COVERED
Final Report
March 27, 1972-Dec. 31, 1973

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
Robert A. Dick, Jackson W. Royal,
Henry K. Simpson, and Robert R. Mackie

8. CONTRACT OR GRANT NUMBER(s)
N00014-72-C-0370

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Human Factors Research, Incorporated
6780 Cortona Drive
Goleta, California 93017

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
61153N; RR042-06;
RR042-06-01
NR154-348

11. CONTROLLING OFFICE NAME AND ADDRESS
Personnel and Training Research Programs
Office of Naval Research (Code 458)
Arlington, Virginia 22217

12. REPORT DATE
June 1, 1974

13. NUMBER OF PAGES
211

14. MONITORING AGENCY NAME & ADDRESS *(if different from Controlling Office)*

15. SECURITY CLASS. *(of this report)*
UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT *(of this Report)*

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT *(of the abstract entered in Block 20, if different from Report)*

18. SUPPLEMENTARY NOTES

19. KEY WORDS *(Continue on reverse side if necessary and identify by block number)*

Aptitude-treatment interaction; Computer-aided instruction; Computer-managed instruction; Digital logic; Educational psychology; Instructional psychology; Learning; Programmed learning; Programmed instruction; Vocational skills.

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

This research program compared computer-based and programmed textbook-based curricula for training students to troubleshoot digital logic circuits. The curricula contained identical theoretical material arranged in identical, logical formats. However, the students in the computer-based curriculum received experience in troubleshooting and interacting with simulations of digital logic circuits driven by the computer,

BEST COPY AVAILABLE

while the students in the text-based curriculum used diagrams of digital logic circuits and written explanations in lieu of demonstrations and troubleshooting exercises.

Prior to training, students took the Navy's General Classification Test (verbal aptitude) and Electronic Technician Selection Test (electronics and mathematics aptitude). Members of matched pairs on the aptitude tests were randomly assigned to the two training treatments.

Two performance criteria were used to measure training effectiveness; one was a multiple-choice written test of theoretical knowledge, and the second was a one-hour session of troubleshooting actual faulty digital logic circuits. Both performance tests were administered twice--once within a week after the student completed the 15-hour course, and again nine weeks after completion of the course.

Several different analyses were used to relate student performance on the written and skill tests to the two aptitude measures and to short-term and long-term retention. Observation and anecdotal evidence suggested that the computer-based curriculum was more interesting and stimulating, especially to the brighter students; however, none of the objective measures showed an advantage for the computer group. In fact, there appeared to be a slight superiority of the programmed text-based curriculum for the students of lower verbal and/or electronics and math aptitude on the long-term retention test in troubleshooting.

BEST COPY AVAILABLE

ACKNOWLEDGMENTS

We wish to acknowledge the support and guidance of Dr. Marshall J. Farr, Director of Personnel and Training Research Programs, ONR. His direction made a substantial impact on the important features of the experiment.

We are very appreciative of the advice and materials that Dr. Bernard Rimland, Director of the Personnel Measurement Research Department, Naval Personnel Research and Development Center, and his staff provided to us in selecting subjects with appropriate aptitudes for this study.

We are grateful to Dr. Howard L. Kitchener, Director of Research, U.S. Justice Department, Bureau of Prisons, and to Warden Frank F. Kenton, Lompoc Federal Correctional Institution, for making the inmates at Lompoc FCI available for the study. We were especially thankful for the daily assistance with myriad logistic details from Donald R. Scott, Superintendent of Education at Lompoc FCI, and Gene Kolakowski, Educational Coordinator.

The authors want to acknowledge the members of our staff who made substantial contributions to this project: Mr. Gene Kelley, Research Support Coordinator; Mr. Robert Nelson, Electronics Engineer; Mr. Brad Stewart, Systems and Applications Programmer; Mr. James Pfeifer, Graphics; and, of the several secretaries who rendered their invaluable skills as amanuenses throughout the project, especially Ms. Kathi Peimann, who waded through (seemingly) endless iterations of the final report without complaint.

TABLE OF CONTENTS

Page

ACKNOWLEDGEMENTS iii

LIST OF FIGURES AND TABLES ix

CHAPTER

I EXECUTIVE SUMMARY 1

II INTRODUCTION. 5

A. Background. 5

B. Relevant Literature 7

1. The Problem of Individual Differences in Training 7

2. Computerized Instruction. 10

(a) Training in General 10

(b) Skill-Oriented Training 12

3. Summary 15

C. Research Objectives and Approach. 16

III DESCRIPTION OF THE EXPERIMENT 19

A. Overview. 19

1. Course Topic. 19

2. Non-Computerized Curriculum 20

3. Computerized Curriculum 20

4. Comparison of the Two Curricula 22

5. Student Aptitudes 23

6. Performance Criteria. 26

B. Experimental Plan 26

TABLE OF CONTENTS (Continued)

CHAPTER Page

IV DETAILED PROCEDURES AND EQUIPMENT DEVELOPMENT . . 29

A. Development of Experimental Curricula 29

1. General Approach. 29

2. Text. 31

3. CII Terminals 33

4. Computer System and Software. 40

5. Performance Criteria. 40

B. Field Plan and Execution. 51

1. Subjects. 51

2. Training and Testing. 55

V RESULTS AND ANALYSES. 59

A. Preliminary Data Analysis 60

B. Multivariate Analysis 69

1. General Discriminant Analysis 71

2. Discriminant Analysis Using Knowledge Measures. 74

3. Discriminant Analysis Using Short-Term Skill Measures. 76

4. Discriminant Analysis Using Long-Term Skill Measures. 78

5. Summary of Results from the Discriminant Analyses. 80

(a) Aptitude Differences. 80

(b) Training Treatment Differences. . . . 80

6. Univariate Analysis 80

VI CONCLUSIONS AND RECOMMENDATIONS 89

TABLE OF CONTENTS (Continued)

Page

REFERENCES 95

APPENDIX

A EXCERPT FROM CHAPTER 5, "R-S FLIP-FLOP," IN THE PTI TEXTBOOK, A PROGRAMMED TEXT IN DIGITAL TECHNOLOGY. A-1

B EXCERPT FROM CHAPTER 5, "R-S FLIP-FLOP," IN THE CII TEXTBOOK, A PROGRAMMED TEXT IN DIGITAL TECHNOLOGY. B-1

C KNOWLEDGE TEST. C-1

Digital Technology. C-3

D ANNOTATED INSTRUCTIONS TO STUDENTS FOR THE SKILL TESTS D-1

Super Logic Problems. D-3

Half Adder Problems D-4

Multiplexer Problems. D-6

Super Logic Problems. D-9

Half Adder Problems (Clear All Shift Registers). D-10

Multiplexer Problems (Clear Ring Counters). . D-12

LIST OF FIGURES AND TABLES

Page

FIGURE

1 General experimental plan 27

2 Project plan: Development of experimental curricula and support material is highlighted . . 30

3 Student at a CII terminal 35

4 Close-up view of CII terminal 37

5 Redcor 785 minicomputer 41

6 Skill test equipment. 45

7 Connections between master box and half-adder circuit 47

8 Project plan: Execution of field study is highlighted 52

9 Layout of classroom 56

10 Short-term knowledge as a function of verbal aptitude and training treatment 62

11 Long-term knowledge as a function of verbal aptitude and training treatment 62

12 Short-term knowledge as a function of math/science aptitude and training treatment 63

13 Long-term knowledge as a function of math/science aptitude and training treatment 63

14 Short-term troubleshooting performance as a function of verbal aptitude and training treatment 66

15 Long-term troubleshooting performance as a function of verbal aptitude and training treatment 66

16 Short-term troubleshooting performance as a function of math/science aptitude and training treatment. 67

LIST OF FIGURES AND TABLES (Continued)

Page

FIGURE

17 Long-term troubleshooting performance as a function of math/science aptitude and training treatment. 67

18 Centroids and 1-sigma centours for 4 groups in first 2 dimensions of reduced discriminant space for summary analysis. 73

19 Centroids and 1-sigma centours for 4 groups in first 2 dimensions of reduced space for knowledge measures. 75

20 Centroids and 1-sigma centours for 4 groups in 3 dimensions of reduced discriminant space for Short-Term Skill Test measures. 77

21 Centroids and 1-sigma centours for 4 groups in 3 dimensions of reduced discriminant space for Long-Term Skill Test measures 79

22 Time to Complete Training as a function of science/math aptitude and training treatment. . . 83

23 Number of Interactions as a function of science/math aptitude and training treatment. 84

24 Pre-Course Knowledge as a function of science/math aptitude and training treatment. 85

25 Time To Complete the Long-Term Skill Test as a function of science/math aptitude and training treatment 85

26 Number of Timed-Out Items on the Long-Term Skill Test as a function of science/math aptitude and training treatment. 85

27 Time To Complete the Long-Term Skill Test as a function of verbal aptitude and training treatment 87

TABLE

1 Comparison of Critical Aspects of the Programmed Text Instruction (PTI) Curriculum and the Computer Integrated Instruction (CII) Curriculum in Digital Logic 24

LIST OF FIGURES AND TABLES (Continued)

Page

TABLE

2 Intercorrelations Among Aptitude Scores, Scores on the Knowledge Tests, and Time to Complete the Skill Tests 64

3 Summary of Analyses of Variance Results Relating 18 Dependent Variables to Training Treatment and Science/Math Aptitude Levels. 82

BEST COPY AVAILABLE

I. EXECUTIVE SUMMARY

Among the most severe problems in current military training are (1) the wide range of trainee aptitudes, (2) the shortage of qualified personnel to teach a multiplicity of subject matters, and (3) the general scarcity of operational equipments available for training practical skills. Many believe that computerized instruction offers the potential for solving these problems in that, theoretically, (1) computerized instruction is flexible enough to provide different instructional strategies for trainees of differing aptitudes, (2) many standardized computerized curricula could be developed that do not require qualified classroom instructors, and (3) computerized instruction could include simulations of operational equipments.

One of the major obstacles to wide implementation of computerized instruction is cost. The primary costs are (1) hardware and software acquisition and maintenance, and (2) professional educators' time in modifying existing courses, or creating new ones, to fit the logical constraints of the computerized approach. Furthermore, there is not a large quantity of objective evidence that the computerized approach is the best of several alternate instructional strategies. Many comparisons between computerized and "conventional" instruction use an unmodified classroom/lecturer approach as the "conventional" basis for comparison. The results of such a comparison confound the benefits of modifying the course with the benefits of using a computer.

The objectives of the present research were (1) to investigate the feasibility of cutting costs in computerized instruction by limiting the computer to necessary roles (e.g., providing simulations of operational equipment, controlling the instructional environment, but *not* disseminating textual information, which can be done less expensively with a textbook);

BEST COPY AVAILABLE

(2) to objectively compare this computerized curriculum with a non-computerized curriculum that contained identical course information in an identical logical format; (3) to make the results of the study relevant to skill training by using a subject matter, troubleshooting digital logic circuits, that emphasized learning a practical skill; and (4) to relate the results to the problem of differing trainee aptitudes.

Two experimental curricula were developed that met the criteria within the objectives outlined above. One used a minicomputer, the other used programmed instruction. The curricula were administered to trainees who were matched on scores on two Navy aptitude tests, the General Classification Test and the Electronic Technician Selection Test. After the courses, trainees were tested for knowledge via a paper-and-pencil test, and for skill via a 1-hour timed test in troubleshooting digital logic circuits. Nine weeks after the courses, knowledge and skill tests were again administered to the trainees.

The results showed that high aptitude students were superior to low aptitude students on all the post-course performance criteria, whether the criteria were measures of acquired knowledge or task performance. The training treatment had no differential effect on the high aptitude students. Low aptitude students in the non-computer curriculum appeared to perform better on certain skill criteria than did low aptitude students in the computerized curriculum. Students in the non-computerized curriculum finished the training sooner than those in the computerized curriculum, regardless of aptitude level. We concluded from the results of the present study, and from certain relevant literature, that (1) high aptitude students are relatively insensitive to different training curricula; (2) low aptitude students are, indeed, sensitive to different training curricula; (3) computerized instruction is not necessarily faster; (4) more, not less, instructor involvement may be the case in computerized instruction,

BEST COPY AVAILABLE

especially at the outset when students are learning to interact with the system; and (5) evidence is accumulating that predicts less expensive computerized instruction in the future.

We recommended that (1) further research on computerized instruction include adequate control curricula for comparison; (2) research on optimizing instruction for individuals of varying aptitude should focus on the lower aptitude trainees; and (3) alternative, less expensive, instructional approaches should be carefully considered before opting for computerized instruction in skill training.

II. INTRODUCTION

The research reported here was motivated by the problems of training skills in military organizations. We experimentally investigated several aspects of the applicability of computerized instruction to solving some of these training problems. The following sections discuss the practical problem background, relevant literature, and our approach.

A. *Background*

Computerized instruction appears to offer the potential for alleviating several long-standing problems in civilian and military education. Both institutions have had difficulty coping with individual differences, but the self-paced instructional sequence, which is, conceptually, at the heart of computerized instruction, is a step toward solving the individual differences problem. Both institutions also suffer varying degrees of difficulty in providing qualified instructors; here, computerized instruction could be of immense value in providing standardized, high quality instruction which can be distributed to many local educational facilities. A third problem, more acute in some military situations, is the absence of up-to-date training equipment. Computers afford great educational potential here in that they can be programmed to simulate operational equipment. Computerized instructional techniques, given appropriate generalized displays and interfacing, can also be brought to bear on this problem.

Training in the Naval Reserve provides a clear example of the potential value of computerized instruction. We use the Naval Reserve as an example, because problems in skill training, which exist to some degree in all military institutions, are acutely present in the Reserve. The individual differences of Naval Reservists in aptitude, rate, level of experience, and recency of experience create a strong requirement for self-paced, individualized instruction. The extreme heterogeneity of the personnel in technical specialities makes it highly improbable that qualified instructors will be available, in sufficient quantity and at the right places, to meet the need. In addition, the high cost of military hardware makes it prohibitive to provide up-to-date equipment and training devices to the large number of Reserve Training Centers scattered throughout the country.

An indication of the multiplicity and magnitude of the Reserve training problem is the fact that there are 132,000 authorized Naval Reserve pay billets in more than 400 Naval Reserve Training Centers spread across the United States. Each training center may, at any given time, be required to provide training for personnel from each of the more than 60 Navy rates. Only rarely is it possible to provide training for a particular pay grade within a rate and almost no consideration can be given to providing training suitable for a particular NEC. Confronted with this problem, Naval Reserve training relies heavily on repeated use of the same written course materials and a very limited amount of "hands-on" training, often with very outmoded equipment. The consequences are not only inadequate training for rapidly changing fleet requirements but very limited motivation as well.

It is tempting to look to computerized instruction to solve training problems of the type posed by the Naval Reserve. Unfortunately, many computerized instructional developments are associated with large computer systems requiring costly initial hardware and software development investments as well as expensive, continuing hardware and software maintenance. Two important questions may be raised here: "Does computerized instruction deliver the benefits that have been hypothesized?" And, if so, "are there means of reducing the cost of computerized instruction to bring it within the grasp of institutions with modest training budgets?"

B. *Relevant Literature*

Two general areas of research are relevant to the questions stated above. One is concerned with the problem of individual differences in training, the other, naturally, with the field of computerized instruction itself.

1. *The Problem of Individual Differences in Training*

The hypothesis that instruction should be tailored to meet the needs of individuals with differing aptitudes, motivation, and other characteristics is intuitively appealing. The basic premise is that not all individuals will maximally benefit from a single kind of instructional treatment; for instance, high aptitude students may do better in an instructional environment that allows a great deal of autonomy than they would in an instructional environment that is very rigid and directive, while the reverse may be true for low aptitude students. Cronbach (1957) provided one of the early discussions of this hypothesis. This area of research has been defined as the Aptitude/Treatment Interaction (ATI) problem.

Bracht (1969) analyzed 90 research studies on ATI. He argued that the only interaction between instructional treatment and student aptitude that was practically significant would be an interaction such as the one described above where one treatment was superior for students at one level of aptitude but inferior for students at another level of aptitude. Bracht called this a "disordinal" interaction. An interaction of this sort would be important to discover, because it would indicate the need for "individualized" training; different training treatments for different aptitude levels.

Bracht contrasted the above type of interaction with what he called an "ordinal" interaction where one of two treatments may be superior for both aptitude levels; however, the difference between the two treatments may be much smaller for one aptitude level than for the other aptitude level. This latter type of interaction may be statistically interesting; however, it would not indicate the need for individualized training; a single training treatment would be best for all aptitude levels.

Bracht found only five studies that showed disordinal interactions and he concluded that in these cases the findings had no clear implications for individualized instruction. Glaser and Resnick (1972) discussed the ATI problem and, along with Bracht, concluded that few or no ATI effects had been solidly demonstrated. Glaser and Resnick concluded that the "...negative results raised significant questions about this area of research."

The following studies, which were not included in the above reviews, suggest that this area of research is not a dead topic. These three studies point to a number of practical problems in training students of high and low aptitude.

Bialek *et al.* (1973) reported some very interesting work exploring the best way to train Army men of differing aptitudes. They were especially concerned with Level IV trainees (those scoring between 10 and 30 on the Armed Forces Qualification Test), but they also explored the middle and upper aptitude ranges. This rather large research program on ATI began with a relatively rigorous factorial approach through systematic manipulation of various aptitude, media, and subject matter variables. These investigators eventually concluded that this scientific and systematic approach became too unwieldy and expensive. They then switched to what they called an "optimization strategy" where they hypothesized the "best" training strategy for teaching low aptitude students and a different "best" training strategy for high aptitude students. For both the high and the low aptitude strategies, they proceeded through successive iterations of tryout and modification in order to converge upon "optimal training strategies" for each aptitude level. Briefly, Bialek arrived at the following conclusions: (1) Low aptitude students do poorly in experimental studies because they do not appear to see the relevance of the learning task and therefore are not well motivated; (2) low aptitude students do best under conditions that maximize interaction with a live instructor; (3) low aptitude students do not do well with printed material (e.g., programmed text); and (4) high aptitude students do best under conditions that permit autonomy and they do not appear to need costly audio-visual equipment and similar materials.

McFann (1971) emphasized the need for research on training personnel of high and low aptitudes in military organizations, especially the Army, by noting that "an important difference between Army training and public education is that the Army must utilize the products of its instructional system." Working on the same project as Bialek, McFann reported that an associate, Grimsley, made the interesting finding that for medium and high ability trainees, the fidelity of a training simulator, with respect to the actual operational equipment, could be very low with no adverse effect on the time needed for training, the level of proficiency, the amount remembered over time, or the time needed for retraining. However, the fidelity of the training device was found to be very important in the training of low ability personnel. For the low ability group, the higher the fidelity of the device, the greater the proficiency achieved, and the less time required for training.

Dick and Latta (1969) reported an interesting result in training two non-overlapping groups of low and high math aptitude junior high level students in learning certain mathematical concepts. These investigators compared paper-and-pencil programmed text instruction with computer-aided instruction that used a CRT to display text material. The type of instructional method made little difference in the proficiency achieved by the high aptitude students, but the low aptitude students achieved higher proficiency with the programmed instruction treatment. This phenomenon persisted in the results of a long-term retention test for these students.

We wish to conclude this very brief overview of the ATI problem with the following summation: (1) The ATI problem is not nearly a dead issue as suggested by Glaser and Resnick; the problems of training students of differing aptitudes are very real in practical training situations such as those faced by military organizations; (2) further, there is evidence for the following generalization: High aptitude students are not terribly sensitive to instructional treatments; they appear to do well with a wide variety of training methods or media. However, low aptitude students are indeed sensitive to the training treatment, and the fact that most military organizations anticipate an increasing proportion of low aptitude personnel makes the problem of finding optimal training strategies for low aptitude students a crucial one.

2. *Computerized Instruction*

(a) *Training in General.* The advent of computer technology was seen by many as a possible panacea for the problem of individualizing instruction to meet the needs of students with differing aptitudes. Surely the computer with its large storage capacity, fast retrieval time, and flexibility in programming would be the teacher who could be all things to all men.

Two broad approaches to utilizing computers in education emerged: One was Computer-Assisted Instruction (CAI) where the computer, in some sense, replaced the instructor. The other approach was Computer-Managed Instruction (CMI) where the computer became a tool to be used by an instructor as a bookkeeping aid in keeping track of his students' progress. We will not attempt to review the voluminous literature on CAI and CMI. Stoluro (1969), Suppes *et al.* (1968), Cooley and Glaser (1969), Hansen (1970), and Salisbury (1971), among others, have adequately reviewed the CAI literature, extolled their philosophies for proceeding with CAI research, and described their own programs. Other reports include Hickey and Newton's (1967) review of the results of the CAI information exchange program sponsored by the Office of Naval Research through a contract to ENTELEK, Incorporated. Hickey (1970) provides an overview of the entire ENTELEK program including the conferences and literature surveys conducted under this project. Farr (1972) reviewed the CAI research and development programs sponsored by Personnel and Training Research Programs, within the Office of Naval Research.

In addition to general overviews of CAI work, the following two reviews concern specific CAI development programs. Dwyer (1971) discusses the NEWBASIC/CATALYST program developed by the University of Pittsburgh. This is essentially a complex software package. Hammond (1972) discusses two advanced hardware developments in CAI; one is TICCIT (Time-shared Interactive Computer Controlled Information Television), which uses television as the primary output display; and PLATO (Programmed Logic for Automatic Teaching Operations), which uses a specially developed display called the "PLASMA panel" that allows very fine resolution.

The literature cited above is but a small portion of the CAI literature and is mainly provided for the interested reader who wishes to use it as a jumping-off point for further review. A wide range of specific and general conclusions may be drawn from these reports. The following points bear on the present study.

There is general concern about the cost of computerized instruction. High visibility expenditures are hardware and software costs in developing and maintaining CAI and CMI systems.

A less conspicuous, but no less avoidable, cost is that of professional educators' time in reconstructing old courses, or developing new courses, to fit CAI and CMI paradigms. The need for course reconstruction in computerized training has also led to problems in comparing the effectiveness of computerized training with "conventional" training. The studies that have compared the results of computerized instruction with non-computerized instruction have often confounded the results due to course reorganization with the results due to using a computer in the instructional paradigm. An example of this will be given in the next section.

In general, the initial flurry of activity and excitement over computerized instruction has settled down. Many investigators are now turning to the long arduous task of developing a sound theory of instruction and implementing it. That implementation, quite probably, will involve computerized instruction. Before turning from this topic, we wish to point to a bright spot on the horizon. Given that a sound theory of instruction develops, where computers play some important role, it may be possible to implement that theory without the expense of the current crop of large-scale CAI systems. Thomas (1973) describes the development of a computer-aided instruction system using a minicomputer. His cost comparisons for large and small computerized instructional systems show comparable costs per hour for the large and small systems but a substantial savings in initial acquisition for the small system. Brebner (1973) describes another computer-assisted instructional system built around a relatively small computer, a PDP-8/I. Our own efforts along these lines will be described in detail later.

(b) *Skill-Oriented Training.* The number of investigators who have focused on the problems involved in training practical skills is a relatively small proportion of the investigators who comprise the fields of education, educational psychology, and instructional psychology. Therefore, there has been relatively little computerized instruction work done in these fields that bears directly upon skill training; the work that has been done was usually funded through contracts with military agencies. The following examples are given to characterize skill research of this nature.

Rigney *et al.* (1972) reported on research and development on practical skill training in a computer-aided environment, performed at the University of Southern California Behavioral Technological Laboratories. Briefly, the approach here was to have a front panel copy of a unit of operational equipment standing alongside a student terminal connected to a computer system. A student "conversed" with a software package that guided him through exercises in button pushing and knob turning on the front panel of the operational equipment.

There appear to be two main emphases in Rigney's approach: The first is to develop a theory and logic for task analysis that will apply to a wide variety of specific skills. Much of the work involves the breakdown of skills and training problems into three elements, "goal descriptions, action descriptions, and clustering operators," and the delineation of all possible relationships between actions and goals. Rigney's second main emphasis has been to develop sophisticated programs that are general and embody his approach to task analysis. These programs then operate on "data modules" which are the simple lists that are specific to a given problem or task area. Once Rigney is finished with his work, he would have a logic for task analysis and a set of general programs so that, for example, an instructor who wished to teach the use of an oscilloscope would (1) analyze the task according to a well worked out task analysis logic, (2) generate the list for the specific data module for teaching this task, (3) plug the data module into Rigney's general program, (4) sit the student down at a terminal with a copy of the oscilloscope alongside, and (5) press "run" on the computerizer training system. This may be an over-simplification of Rigney's approach; however, it appears to characterize the goals of his program. His main thrust lies in the philosophy and theory of task analysis and the development of sophisticated general-purpose software to implement the theory.

Another group, at the Naval Personnel Research and Development Center (NPRDC), has taken a somewhat different tack. Instead of addressing the general problem of skill analysis, as Rigney has done, they plunged ahead with generating one solution to a specific practical training problem. Ford *et al.* (1972) reported on the development of a CAI approach to training five of the eight topics at Navy Basic Electricity/Electronics School. They compared CAI training with regular classroom lecture training and found that the CAI approach resulted in (1) reduced classroom time (39%-54% less) and (2) better scores on the School Examination as well as on a Supplemental Test. Significant improvements for the CAI groups were evident on nearly all criteria, on all topics. They also showed that pairs of students working at a single CAI terminal performed as well as one student per terminal. These investigators performed several iterations of tryout and revision in order to optimize the set of CAI curriculums for the five topics.

Now, Rigney's group and Ford's group represent two very different approaches: On the one hand, Rigney's group took the somewhat academic approach of studying the theoretical parameters behind the problem of computerized skilled training and software development. On the other hand, Ford's group took the more applied approach of directly generating a solution to a training problem using what appeared to be the best techniques currently available. At this point, it is not clear which approach is better; it is not even clear that one can make that sort of value judgment about these two approaches. Rigney has attacked the very difficult problem of developing a comprehensive, logical approach to task analysis that may generalize to a wide variety of skill training problems. At the same time, he is developing the means for implementing the results of his findings on task analysis. However, Rigney has not performed comprehensive comparisons between his approach and others.

Ford's group has made the comparison, and the results of their efforts are currently in use in practical training situations; however, this approach also has drawbacks. They have attacked a specific set of training problems and their solution may not generalize as well as Rigney's. Also, their large-scale comparison may be criticized on the grounds discussed earlier: They have confounded the results of course reconstruction with the results of using a computerized curriculum. They compared the final result of several iterations of CAI curriculum revision with traditional Navy classroom training; it is not at all clear whether the improvement in the CAI condition was due to the intensive and extensive course revision or due to the use of the computer.

This latter criticism is reinforced by the results of another program at NPRDC. Stern (1972) reports the results of a program to develop and evaluate performance-oriented test equipment training procedures. He showed that a self-paced workbook approach to training the use of test equipment was superior to the typical lecture-lab approach in Surface Sonar Technician (ST) A-1 Training School. Here is an example that shows that well-thought-out course reconstruction does not necessarily need a computer in order to show training results that are superior to the typical classroom lecture and laboratory approach.

3. *Summary*

The above review of the literature is by no means exhaustive. We intended simply to outline some of the primary problems in the application of computerized instruction to skill training. We have shown that a critical problem is the relationship of an instructional method to the individual characteristics of the trainee. This is particularly important in the case of low aptitude trainees. We have focused upon the problems in training practical skills and showed that there are pitfalls in evaluating the effectiveness of computerized instruction in this area. The next section discusses our experimental approach to these problems.

C. *Research Objectives and Approach*

One objective of this research was to investigate the feasibility of cutting computer costs in computerized education by limiting the computer to only those roles that are absolutely necessary, i.e., where there is no less expensive alternative. For example, many computerized instructional systems use the computer to disseminate textual information where an obviously cheaper alternative exists, the lowly textbook. In this case, the computer is not an absolutely essential part of the computerized instructional system. On the other hand, the control of the instructional environment, i.e., administering tests, evaluating student performance, and prescribing further instruction, are illustrative of cases where the computer may be a cheaper solution than the alternative, a teacher. As described in detail later, we developed a computerized instructional curriculum that shaved computer costs by limiting the computer to only those roles that we thought could be performed best by the computer.

Another objective of this research was to comparatively evaluate this computerized curriculum with a non-computerized curriculum in order to determine what increased effectiveness, if any, resulted from the computerized approach. We went to great extremes to make the comparisons as objective as possible. As discussed above, many investigators, in making similar comparisons, have not provided adequate controls for the course reconstruction involved in developing the computerized curriculum. This has made it impossible to assess the effectiveness of the computer *qua* computer against the "conventional" curriculum. In these cases, the comparison is really between the conventional curriculum and a vastly-modified-course-with-computer curriculum. The present study avoided confounding the effects of course modification in the comparisons of computerized and non-computerized instructional approaches. We did this by modifying the "conventional" course along the same line as the computerized course.

A further objective of this research was to relate the results of this study to the needs of an institution, such as the Navy, that has a high interest in training proficiency in practical skills. Therefore, we selected a course topic, troubleshooting digital logic circuits, that emphasized learning a practical skill that is of considerable importance in many current Navy training courses.

A final objective was to relate the effectiveness of the two instructional treatments to the problem of training students with different aptitudes. Therefore, two of the independent variables in this study were the level of general verbal aptitude and the level of science/math aptitude. The latter measure of ability is used as one of the important predictors of success in Navy courses similar to the course in digital logic developed for this study.

III. DESCRIPTION OF THE EXPERIMENT

A. *Overview*

As explained in the section on research objectives and approach, one of the objectives of this research program was to explore the possibility of minimizing costs in computerized instruction by limiting the computer to only those roles which were essential. Furthermore, we saw this as an opportunity to evaluate the contribution of the computer in computerized instruction by comparing an alternative non-computerized curriculum with a curriculum that utilizes the computer only where necessary. We wanted to evaluate the effectiveness of each of the two alternatives for students of different aptitudes, and we wanted to use a course topic that contained an important skill component so that the results of this study would generalize to the larger problem area of skill training.

1. *Course Topic*

In designing a study to meet these objectives, we chose a topic that was directly relevant to Navy training. Simpson *et al.* (1971) reported on a course on digital logic that was developed by HFR for Sonar Technicians working on the AN/SQS-26 sonar system. This course covers the principles that are basic to understanding the new generation of digital devices. It was chosen as a vehicle for comparing the two instructional approaches in the present study because, intuitively, instruction in this topic should benefit from laboratory experience with real digital logic circuits. This makes it suitable for testing a computerized system that is designed to train skills via simulation of operational equipment. Further, a course in digital logic is inherently interesting to the Navy because it is an important part of many different curricula in the Navy's

Class A and C electronics training schools. Finally, because HFR developed the digital logic course for the AN/SQS-26 Common Core Curriculum, we were in a good position to modify and use it for our present purposes.

2. *Non-Computerized Curriculum*

We chose Programmed Text Instruction (PTI) as the "conventional" curriculum to be used as a basis for comparison in the present study. This seemed to be an excellent comparator for the computerized curriculum because PTI (1) is widely used, (2) is relatively inexpensive, and (3) requires the same sort of logical course construction as required by a computerized curriculum.

A simple, linear-programmed text format was used because of its current use in many instructional contexts; it is a convenient and reliable pedagogical vehicle. Because the purpose of the present experiment was not to compare different PTI formats or modes, we arbitrarily chose one that was convenient and has gained relatively wide acceptance. The only danger was that the PTI format might interact with student aptitudes and become an unwanted secondary source of variability in this study. However, Davis *et al.* (1970) reported no ATI in a study of different modes of PTI. They tested overt versus covert responding, constructed-response versus multiple choice, and feedback versus no feedback. Their null ATI results led us to use one of the simplest PTI modes; it will be discussed in detail later.

3. *Computerized Curriculum*

The experimental curriculum used a small computer to control the learning environment and to drive a display that simulated digital logic circuits and allowed students to control input to the circuits, test internal circuit conditions, and observe output conditions. In the computerized curriculum, students received the bulk of their needed textual information from a programmed text, just as the PTI students did, instead of from a CRT as in many computerized instructional systems.

A computerized instructional system that does not require the storage and display of bulky textual information enjoys several advantages over one that does. Less storage and much less programming are required. A paper or text medium for conveying the bulk of information in a curriculum is cheaply produced, reliably stored, does not require expensive displays, is easily accessed by the average student, if appropriately indexed, and is easily edited or modified. And, probably most important, the text portion of the curriculum can be produced by personnel qualified in the technical area of the course without requiring additional expertise in computer programming. Clearly, a computer is not an absolute necessity for disseminating the bulk of curriculum information; in fact, there are good reasons not to allocate that function to the computer part of a computerized instructional system.

On the other hand, a valid use of the computer may be to control certain of the contingencies in the instructional program; this is particularly true in the context of programmed instruction where it may be desirable to control students' behavior at the many test points. While the *mode* of programmed instruction may not interact with student aptitudes, as pointed out by Davis, the computer may perform a valuable service in forcing students to take remediation when they appear to need it. Much of computerized instruction is really computer-presented programmed instruction. Therefore, we included this aspect of computerized instruction in order to test the possible advantage of computer control of the training environment. The only reasonable alternative here, close tutorial supervision by a live instructor, is too costly.

Another viable use of the computer, and one for which there is no inexpensive alternative, is the simulation of operational equipment. Here the computer can drive a laboratory in which the student may make inputs and observe the consequences. The alternative would be a different set of real operational equipments for each curriculum and a tutor to monitor each student.

We developed a computerized curriculum that filled the specifications discussed above. For convenience, we shall refer to the computerized curriculum used in the present study as a Computer Integrated Instructional (CII) approach; we will arbitrarily define CII as the use of a relatively small, time-shared computer facility to control certain training and testing contingencies for several students working simultaneously and independently and to control individual displays and response terminals that provide students with simulations of operational equipment with which the student may interact. Furthermore, the CII approach incorporates a linear, frame-oriented, programmed text as the primary vehicle for disseminating information to the students. This definition of CII is purely arbitrary and is intended merely for use in this report as an economic reference to the computerized curriculum in the study as opposed to the PTI curriculum. In a broader context, CII is a relatively new term in the computerized instructional literature, but it is still sufficiently ambiguous to allow us to customize its definition for our present purposes.

4. *Comparison of the Two Curricula*

As will be explained in detail later, we took great care to make the comparison between the CII and the PTI curricula fair, *viz*, we wanted the content and logical format of both curricula to be identical so that the only difference between the CII and PTI treatments would be the contribution of the computer to the instructional process. At this point, a comparison of the two instructional treatments will be made in order to complete the overview of exactly what we were trying to accomplish.

Table 1 presents a comparison of some of the critical elements in the two instructional treatments. It shows that students in both curricula received their theoretical instruction in digital logic via hardcopy programmed textbooks; it should be emphasized that the textbook material, organization of the material, and format of the material were nearly identical for the two instructional curricula. The textbook for the PTI curriculum was virtually a verbatim copy of the CII textbook, except that references to the computer system were omitted, and diagrams and truth tables were inserted for the PTI students where the CII students would look at diagrams on their display and interact with the dynamic circuits. These differences are discussed in considerable detail in the section on text development. The point emphasized here is that a great deal of attention was given to equating the two curricula for content, organization, and format. We wanted to isolate and reduce the differences between the two curricula to only those that represent the computer-based instructional system's potential advantages, and to test whether those advantages would be realized.

5. *Student Aptitudes*

We did not want to concern ourselves with the theoretical aspects of ATI, for that could quickly bog down our otherwise straightforward experimental interests. We felt, however, as a practical matter, that the results of a comparison between two instructional approaches should at the very least be related to the general verbal aptitudes of the students. Going one step beyond this, we felt that the results of a comparison between curricula should also be related to students' aptitudes that are most likely related to the course topic.

Because we wanted to generalize the results of this study to the population of Navy personnel, we chose two Navy aptitude tests in order to assess general verbal aptitude and aptitudes related to the course topic, digital electronics.

TABLE 1

COMPARISON OF CRITICAL ASPECTS OF THE PROGRAMMED TEXT INSTRUCTION (PTI) CURRICULUM AND THE COMPUTER INTEGRATED INSTRUCTION (CII) CURRICULUM IN DIGITAL LOGIC

<table>
<tr><th>PTI</th><th>CII</th></tr>
<tr><td colspan="2">Hard-copy programmed textbook on theory in digital logic.</td></tr>
<tr><td colspan="2">Hard-copy question frames interspersed among information frames.</td></tr>
<tr><td>Student conceives his responses to questions.</td><td>Student types his responses to questions.</td></tr>
<tr><td>Hard-copy feedback frames follow question frames.</td><td>Computer controlled display of feedback after student responds.</td></tr>
<tr><td colspan="2">Errors result in a branch back to an information frame, or a branch forward to remediation. Eventually, the question is repeated.</td></tr>
<tr><td>Student may ignore the branch and the suggested exercise; he may proceed without correctly answering the question.</td><td>Student cannot ignore the branch and he must perform the suggested exercises; he cannot proceed without correctly answering the question.</td></tr>
<tr><td>Hard-copy demonstration frames utilize diagrams and truth tables to demonstrate digital logic principles and circuits.</td><td>Computer-driven general displays utilize plastic overlay diagrams to present dynamic demonstrations of digital logic principles and operating circuits. Students interact with system.</td></tr>
<tr><td>Hard-copy troubleshooting frames utilize diagrams and truth tables to simulate faulty circuits. Student locates fault.</td><td>Computer-driven displays utilize plastic overlay diagrams to present dynamic simulations of faulty circuits. Students interact with system to test circuit components and locate faults.</td></tr>
</table>

TABLE 1 (Continued)

PTI	CII
Student errors in troubleshooting result in a branch back to a prior information frame or demonstration, or a branch forward to remediation. Eventually, the troubleshooting exercise is repeated.	
Student may ignore the branch and suggested exercise; he may proceed without correctly troubleshooting the faulty circuit.	Student cannot ignore the branch and he must perform the suggested exercise; he cannot proceed without correctly troubleshooting the faulty circuit.

The two Navy tests were the General Classification Test (GCT) and the Electronic Technician Selection Test (ETST). The latter is, in reality, a science background test with fairly heavy loadings in math and electronics. Hereafter, we will refer to scores on the ETST as reflecting "science/math aptitude"; and scores on the GCT as reflecting "verbal aptitude."

6. *Performance Criteria*

After a student has completed a training course, the question of importance is: "Can he perform the operational task?" While the most obvious method of answering this question is to confront the student with the operational task, it is often not possible or convenient to do this. Therefore, paper and pencil "knowledge" tests are widely used as surrogates for an actual test of performance. In the present study, we used one such surrogate criterion, a multiple-choice Knowledge Test. We also used a performance test that was very nearly like the operational task of interest. This was a Skill Test that required each student to troubleshoot faulty digital logic circuits under the observation of a test proctor who scored his errors and measured the time required to identify the various faults.

It is of obvious operational importance that the training also produces *retention* of skills; in many operational contexts, the opportunity to exercise learned skills and to receive added reinforcement is limited or sporadic. Therefore, we administered the Knowledge and Skill Tests both at the end of training and again nine weeks later in order to assess the longer-term effects of the two curricula.

The following sections discuss the experimental plan, the details of the curricula development, and the results.

B. *Experimental Plan*

Figure 1 shows a flow chart of the general experimental plan. Each of the activities in Figure 1 will be discussed

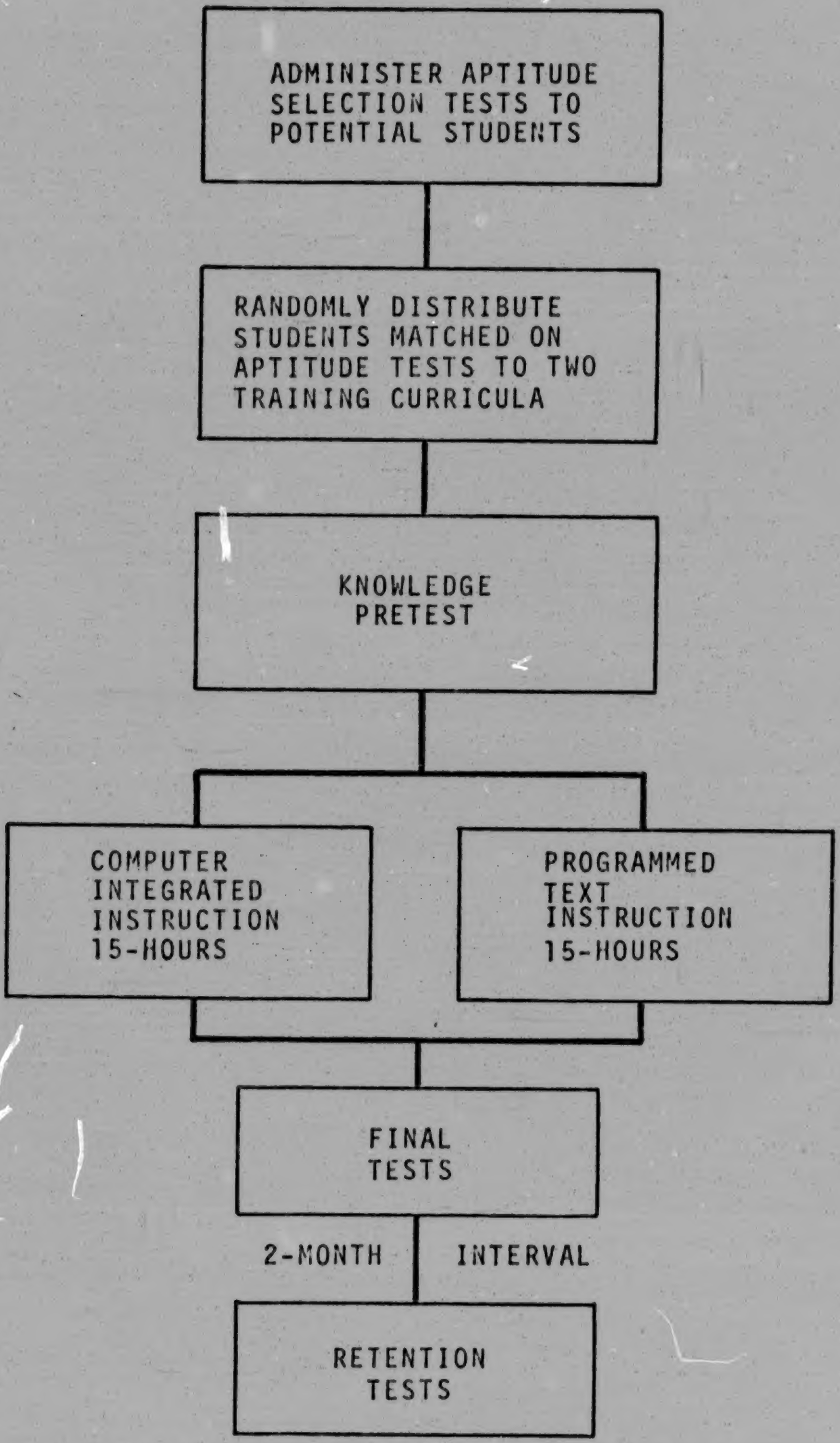

ADMINISTER APTITUDE SELECTION TESTS TO POTENTIAL STUDENTS
RANDOMLY DISTRIBUTE STUDENTS MATCHED ON APTITUDE TESTS TO TWO TRAINING CURRICULA
KNOWLEDGE PRETEST
COMPUTER INTEGRATED INSTRUCTION 15-HOURS
PROGRAMMED TEXT INSTRUCTION 15-HOURS
FINAL TESTS
2-MONTH INTERVAL
RETENTION TESTS

Figure 1. General experimental plan.

in considerable detail in later sections of this report; here we wish to briefly summarize each activity so that the reader may keep in mind the overall plan as he progresses through the somewhat detailed material ahead.

The two aptitude tests were administered to a population of volunteers for the study at the Federal Correctional Institution at Lompoc, California. The characteristics of this population also will be discussed later.

The scores of the selection or aptitude tests were analyzed in order to create matched pairs of students who were equated on both verbal aptitude and science/math aptitude. The members of each pair then were randomly distributed, one to the CII curriculum and one to the PTI curriculum.

Prior to the beginning of the training sessions, all students were administered a knowledge pretest to provide something of a base line for measuring the effects of training. Then they were given five 3-hour training sessions in digital logic theory and faulty logic circuit troubleshooting. Half of the students received the CII curriculum and half received the PTI curriculum. The training sessions were conducted in small group sessions that included four CII students and four PTI students in the classroom at any given time. The room was divided in half, and one proctor monitored both groups.

After two such groups of students completed the training sessions, they received two final tests, the paper and pencil Knowledge Test and the Skill Test involving the troubleshooting of faulty digital logic circuits in specially-created test equipment. No feedback was given for the Knowledge Test but feedback was inherent to the Skill Test. After an interval of 2 months, the students again were given the Knowledge Test, which was identical to the one previously taken, and a new Skill Test, which required troubleshooting of circuits identical to those used in the prior performance tests but with different faults.

IV. DETAILED PROCEDURES AND EQUIPMENT DEVELOPMENT

A. *Development of Experimental Curricula*

1. *General Approach*

We have stated that our intent was to produce two experimental curricula that would be as equivalent as possible with the exception of the variables of experimental interest. Figure 2 shows the overall project plan. The development of the experimental curricula and the necessary support material is highlighted in this project plan. The critical path is shown with the bold arrows.

Because the CII approach had the most stringent format requirement, the specifications for the CII curriculum and related text were developed first.

The next step was the development of the specifications for the necessary software and hardware modifications to an existing computerized instructional system that HFR had previously developed for other research (Mecherikoff, 1974). Subsequent steps on the critical path included (1) execution of the specified modifications, (2) writing the computer code to control the CII training environment, and (3) pilot work to check out the system and the curriculum code.

After the curriculum for the CII students was relatively stable, a modification of that curriculum was made to meet the needs of the PTI approach. Basically, the PTI curriculum was generated by (1) excising all references to the computer in the CII text and (2) substituting diagrams, truth tables, and short discussions at the points in the CII curriculum where CII students would interact with the laboratory simulations.

Other activities in the development of the experimental curricula included the development of displays for the CII

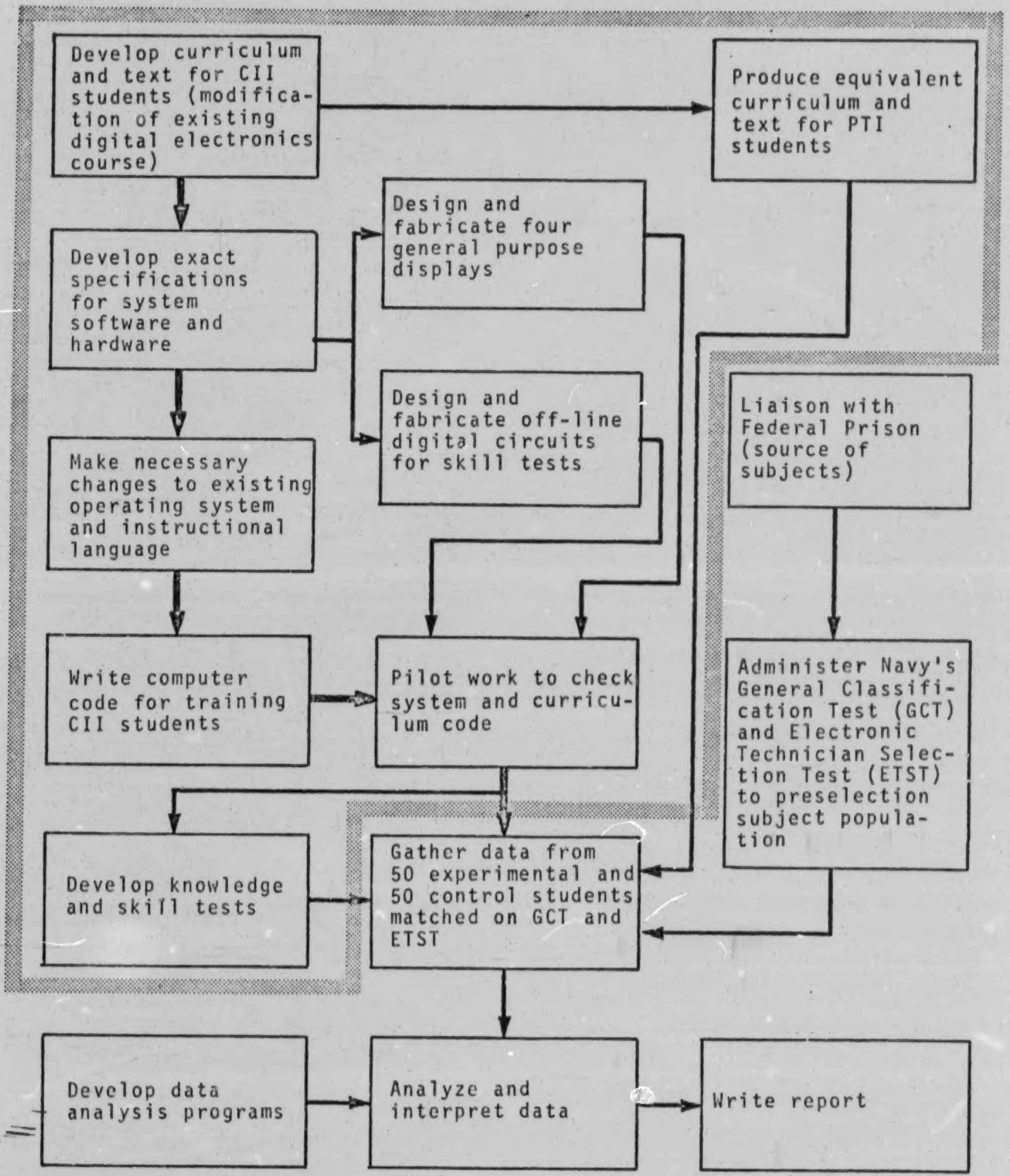

Develop curriculum and text for CII students (modification of existing digital electronics course)
Produce equivalent curriculum and text for PTI students
Design and fabricate four general purpose displays
Develop exact specifications for system software and hardware
Design and fabricate off-line digital circuits for skill tests
Liaison with Federal Prison (source of subjects)
Make necessary changes to existing operating system and instructional language
Write computer code for training CII students
Pilot work to check system and curriculum code
Administer Navy's General Classification Test (GCT) and Electronic Technician Selection Test (ETST) to preselection subject population
Develop knowledge and skill tests
Gather data from 50 experimental and 50 control students matched on GCT and ETST
Develop data analysis programs
Analyze and interpret data
Write report

Figure 2. Project plan: Development of experimental curricula and support material is highlighted.

curriculum, performance criteria, and special equipment for the skill tests.

2. *Text*

A linear programmed text was the basic vehicle for both curricula. Question frames were interspersed among information frames; questions were multiple choice with from two to four alternatives. An incorrect answer resulted in a branch back to an information frame or a branch to a separate section containing remedial information frames. Correct answers resulted in the student going on to the next information frame. In addition to information frames, special demonstration frames were constructed. In these, specific circuits were used as vehicles to demonstrate the principles that had been discussed in information frames. In the PTI curriculum, the demonstration frames used explanations, truth tables, and line-drawing diagrams to demonstrate the operation of various circuits. In the CII curriculum, the demonstrations used explanations in the text, simulated circuits on the displays at the student terminal, and student interaction with the system. His inputs were interpreted by the computing system and would result in state changes at various points in the digital logic circuits on the display.

There was also a special kind of question frame called a Troubleshooting Exercise. Here, a circuit with a fault was presented and the student's task was to identify the faulty component in the circuit or the aspect of the circuit's logic which was faulty. For the PTI students, faults were indicated by errors in the truth table associated with the circuit. For the CII student, faults were indicated by the display showing erroneous logic states at various points in the circuit. A student's performance in troubleshooting was evaluated by his answer to a question that immediately followed each troubleshooting exercise. Again, a multiple-choice format was used with an incorrect response resulting in a repeat of a demonstration or information frame. Eventually, the student had to repeat the troubleshooting exercise. Correct answers allowed the student to proceed.

The CII students were completely captured by the system; they were not allowed to proceed without correctly answering questions. Errors forced the student to go back to the appropriate demonstration, repeat the demonstration, return to the question, and correctly answer it. However, the PTI students, if they were so inclined, could ignore the branching suggestion and the exercise repeats.

The text was divided into six volumes; this was done in order not to intimidate the students when they began the course. Although the course could be completed easily within the 15-hour time limit, the text comprised a rather imposing mass of material. The following list of lessons will give the reader some idea of the material covered in the curriculum:

Volume	Lesson No.	Lesson Title
I	1	Introduction
II	2	OR Gate
	3	AND Gate
III	4	Inverters and the NOR and NAND Gates
	5	Equivalent Logic Functions
IV	6	Combination Logic Functions
	7	R-S Flip-Flop
V	8	Clocked R-S Flip-Flop
	9	D Flip-Flop
	10	J-K Flip-Flop
VI	11	Shift Register
	12	Ring Counter
	13	Divider
	14	Multiplexers

It should be evident that this curriculum takes the student from the very basics of digital logic through most of the common topics and finally to a fairly sophisticated understanding of digital logic in the context of ring counters, dividers, and multiplexers. At first, we were worried that it might not be possible to adequately present this material within the 15-hour time frame; however, pilot work with several students showed that persons of average intelligence could work through the programmed text well within our desired time limit. We felt that it was necessary to present a fairly extensive curriculum in order to tax the abilities of the brighter students and to provide a large base of knowledge to serve as a vehicle for our later tests. On the other hand, we did not want to expend a great deal of costly subject and experimenter time on a much longer curriculum. Given these competing factors, a 15-hour course, comprising the range of sophistication represented by the topics listed above, appeared to be a good compromise.

Appendix A contains an excerpt from Lesson 5, "R-S Flip-Flop," for the PTI text. Appendix B contains an excerpt of the same material from the CII text. The reader is invited to compare the two excerpts to see the similarities and differences between the CII and the PTI texts, and to get a general feeling for the digital logic course that was developed.

3. *CII Terminals*

Figure 3 shows a student sitting at a CII terminal; the terminal comprises a keyboard, a 16-light message display, a 3-digit display, and a "lab display" for presenting the digital logic circuits. The student read his text at the terminal and interacted with the system at points indicated in his text. Figure 4 shows a close-up of the terminal; the lab display uses plastic overlays imprinted with the various digital logic circuits. A matrix of light-emitting diodes

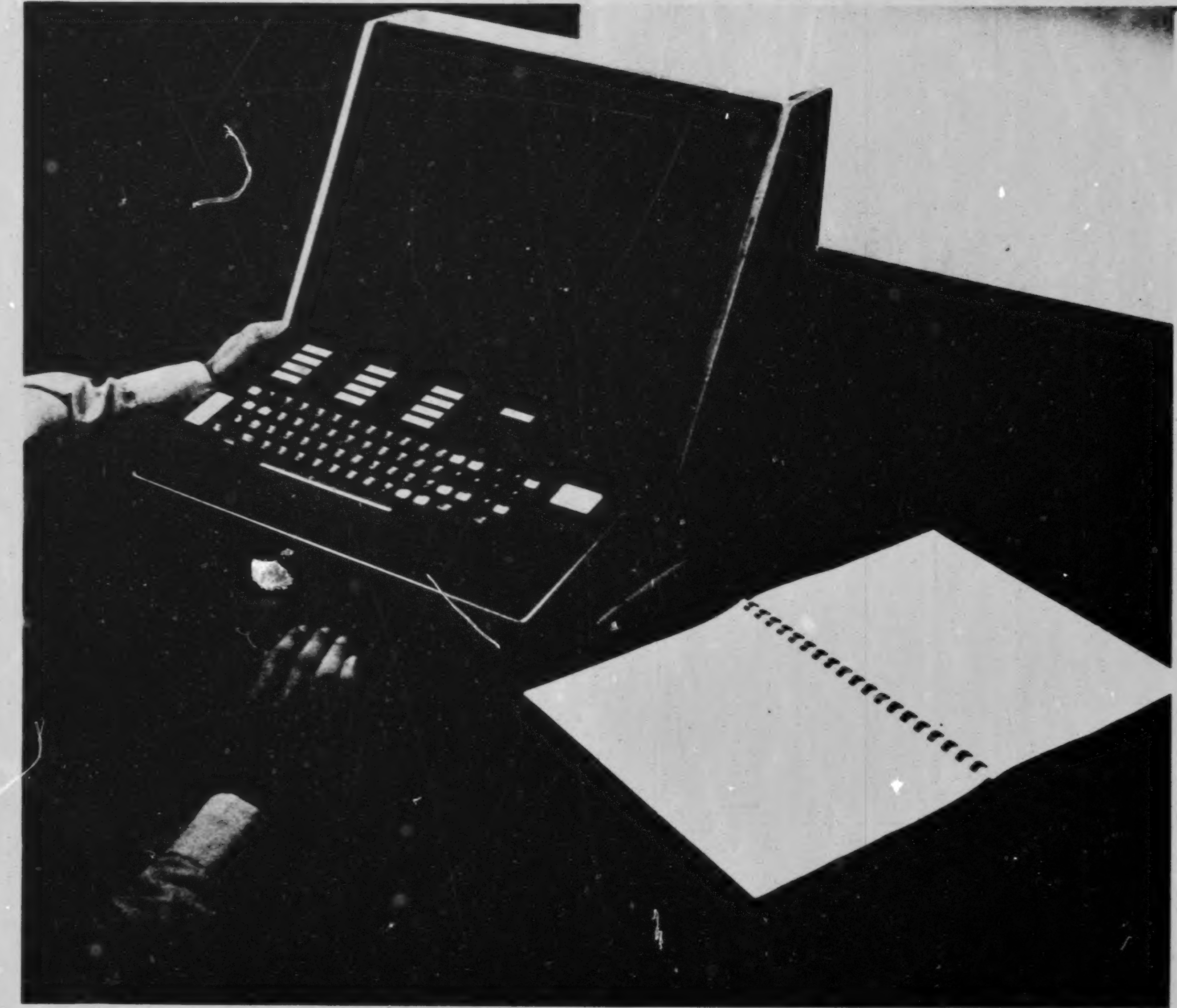


Figure 3. Student at a CII terminal.

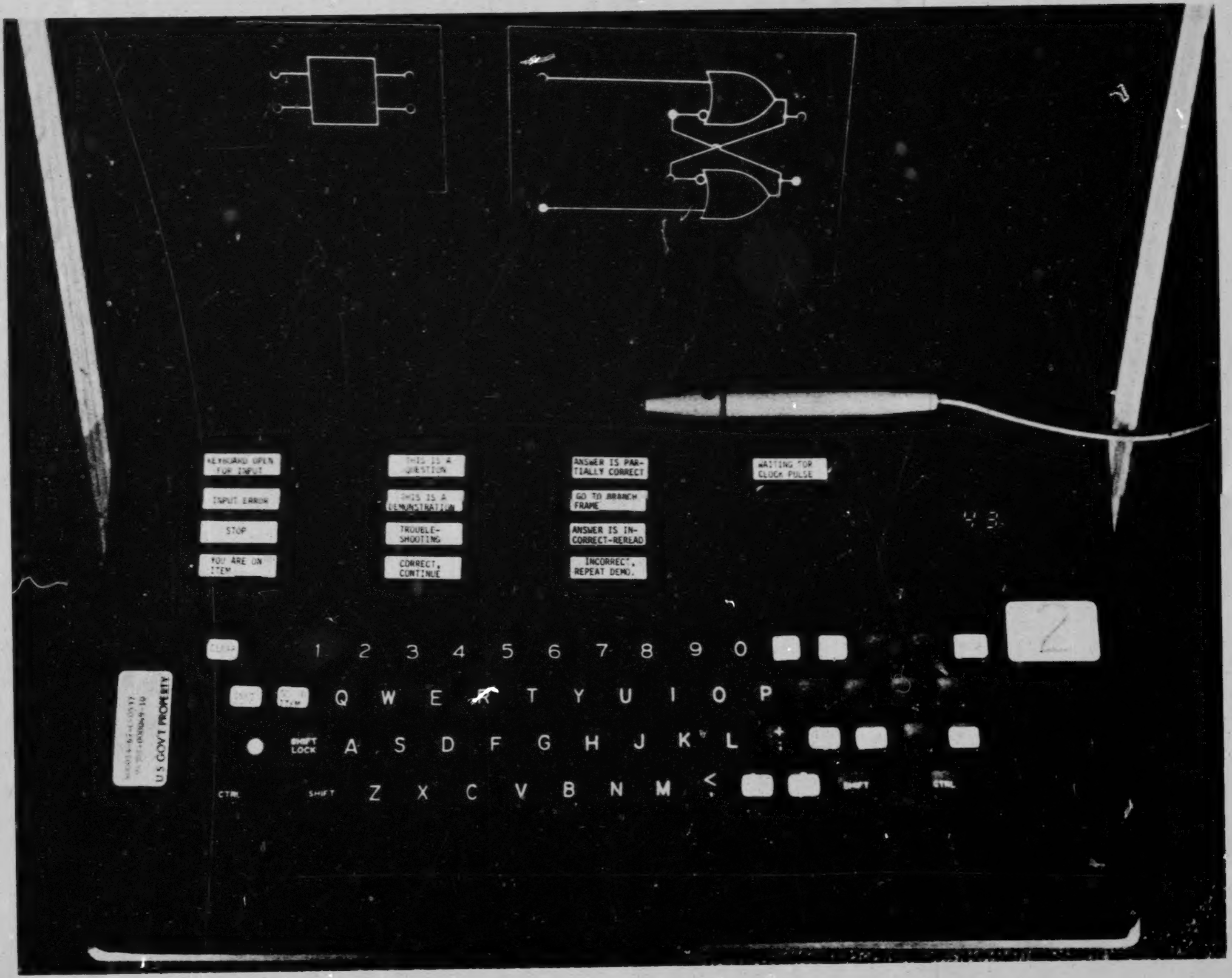

KEYBOARD OPEN FOR INPUT
INPUT ERROR
STOP
YOU ARE ON ITEM
THIS IS A QUESTION
THIS IS A DEMONSTRATION
TROUBLE-SHOOTING
CORRECT, CONTINUE
ANSWER IS PARTIALLY CORRECT
GO TO BRANCH FRAME
ANSWER IS INCORRECT-REREAD
INCORRECT, REPEAT DEMO.
WAITING FOR CLOCK PULSE
U S GOVT PROPERTY

Figure 4. Close-up view of CII terminal.

beneath the overlays was driven by the computer system to indicate the logical states (on = "true," off = "false") at various points in the logic circuits. For troubleshooting exercises, a probe was used to test logic states at different points in a "faulty" logic circuit. The probe made contact with metallic buttons behind the plastic overlays. The computer controls the state values for these buttons.

The overlay in Figure 4 shows the circuit for an R-S Flip-Flop, and it is part of the CII curriculum for the text excerpt comprising Appendix B. An annotation in Appendix B will indicate to the reader where the overlay in Figure 4 is used by the student.

We felt it desirable to minimize the mechanical aspects of a student's interaction with the system. Obviously, a considerable amount of non-pedagogically oriented interaction with the computer system would unfairly disfavor the CII approach when compared with the PTI approach in a closely controlled experiment. Also, we did not want to make the CII curriculum an exercise in typing skill. Therefore, typing at the terminal was minimized by making most responses a series of one or two key pushes. We even assigned one special key, an "=0" value, and another special key, an "=1" value, so that the student would not have to hit two keys for an input specification to a logic circuit. The reader may wish to look again at Appendix B where the excerpt from Lesson 5 for the CII students shows the response reminders that we provided in the left-hand margin of each frame that required interaction with the system. A comparison of those response reminders with the keyboard shown in Figure 4 will reveal that very little typing skill was necessary to interact with the system.

Budget constraints prevented us from developing really general-purpose displays for this project. Because this was a research study, rather than development of a system prototype, it was not really necessary to develop the sort of general display that a vendor for such a system would. The needs of many different curricula would dictate a very general-purpose display; however, for the present study we only required a display sufficiently versatile to represent and demonstrate the range of logic circuits in the experimental course. The matrix of 32 light-emitting diodes driven by the computer and the digital logic circuits printed on plastic overlays met this requirement without making immodest inroads into our equipment budget.

4. *Computer System and Software*

Figure 5 shows the Redcor 785 minicomputer, which was the heart of the system. It has 12,000 words of core storage, a magnetic tape unit, teletype or card input, and considerable custom interfacing for a variety of real-time experimental environments. In the present study, it was connected to four student terminals like the one shown in Figures 3 and 4.

The Redcor runs under a fully resident, multi-programming operating system that is similar in concept to IBM O/S 360. This executive system and curricular programming language that uses easy mneumonics were both developed in-house for other research programs. They have been well documented by Mecherikoff (1974).

The present study required some minor modifications to the interpretive curricular language. Beyond that, the bulk of software development for the present study involved writing the specific program, written in the curricular language, to control the CII environment.

5. *Performance Criteria*

Two kinds of tests were used to evaluate student performance after they had completed the course. The first was a paper-and-pencil Knowledge Test that contained 40, four-alternative, multiple-choice questions. This test was given twice to the

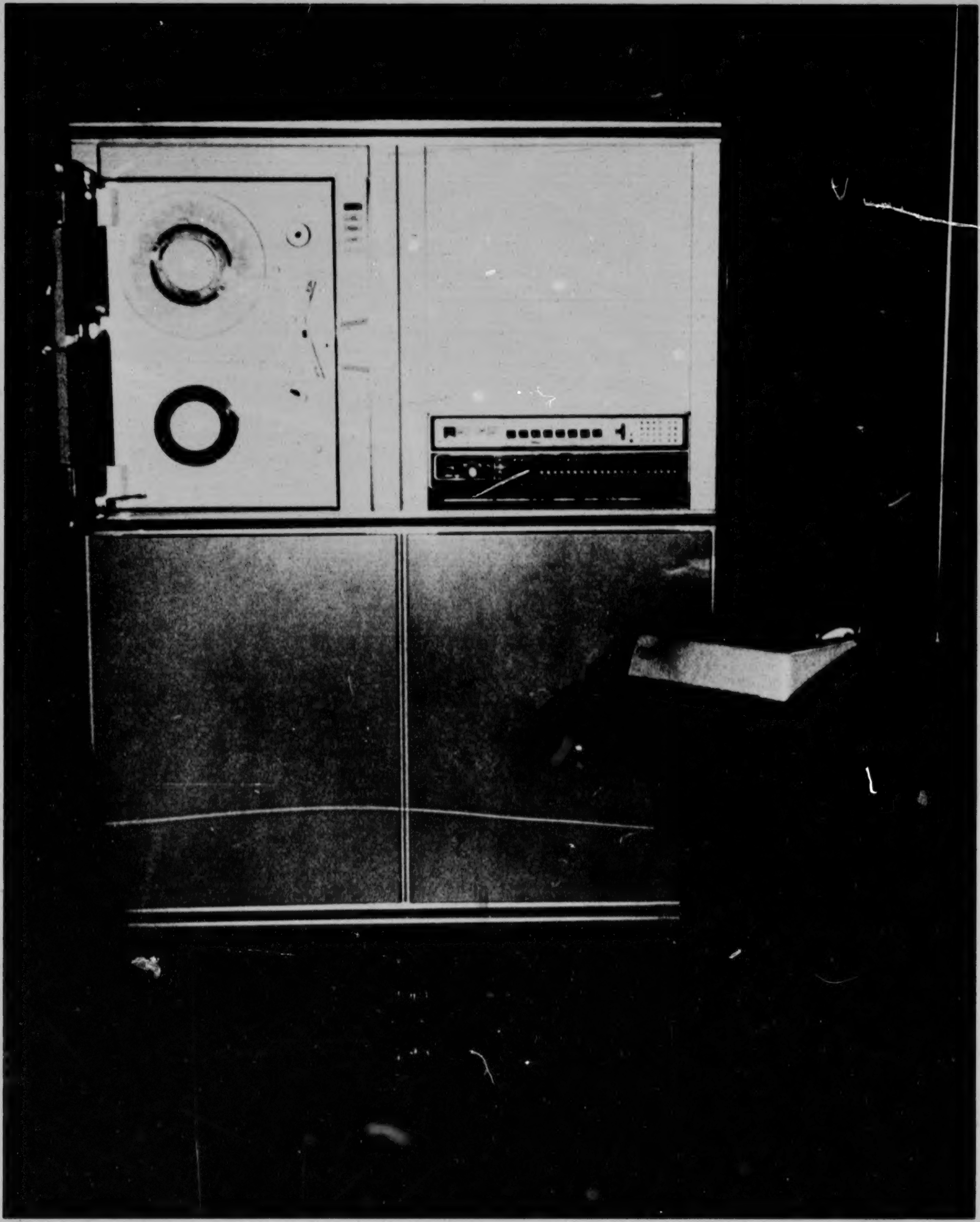


Figure 5. Redcor 785 minicomputer.

students during the study--subsequent to completing the course as a "final" knowledge test and as a follow-up knowledge test two months later. By using the same test on both occasions, we avoided the problem of reliability and content differences between alternate test forms. A copy of the Knowledge Test is presented in Appendix C.

Twenty questions were randomly selected from the Knowledge Test for use as a knowledge pretest. No feedback was given to students on the pretest, the final test, or the long-term retention test.

The second type of test for evaluating student performance was a Skill Test in troubleshooting digital logic circuits. Three special, stand-alone circuits were constructed for the troubleshooting tests. They allowed the experimenter to introduce a variety of faults into each of the logic circuits. Figure 6 shows the three circuit boxes with a master power and control box. One of the test circuits is a half-adder, another is a multiplexer, and a third is a set of four relatively simple combination functions. Figure 7 shows the master box connected to the half-adder. In some cases, the experimenter wired up the test circuit; in others, the student was instructed to make certain connections. Each test circuit box contained a hidden set of switches which allowed the experimenter to introduce different faults in the circuit. Appendix D contains the instructions to students for the Skill Tests; these instructions are annotated to show the nature of each test fault and an example of an acceptable correct answer from the student.

Upon completion of the course, the Skill Test was administered to students individually; this required approximately one hour. Students were given problems using each of the three test circuits. A problem usually required the student to manipulate the circuit, making inputs and testing the results, in order to detect and identify a fault. In some

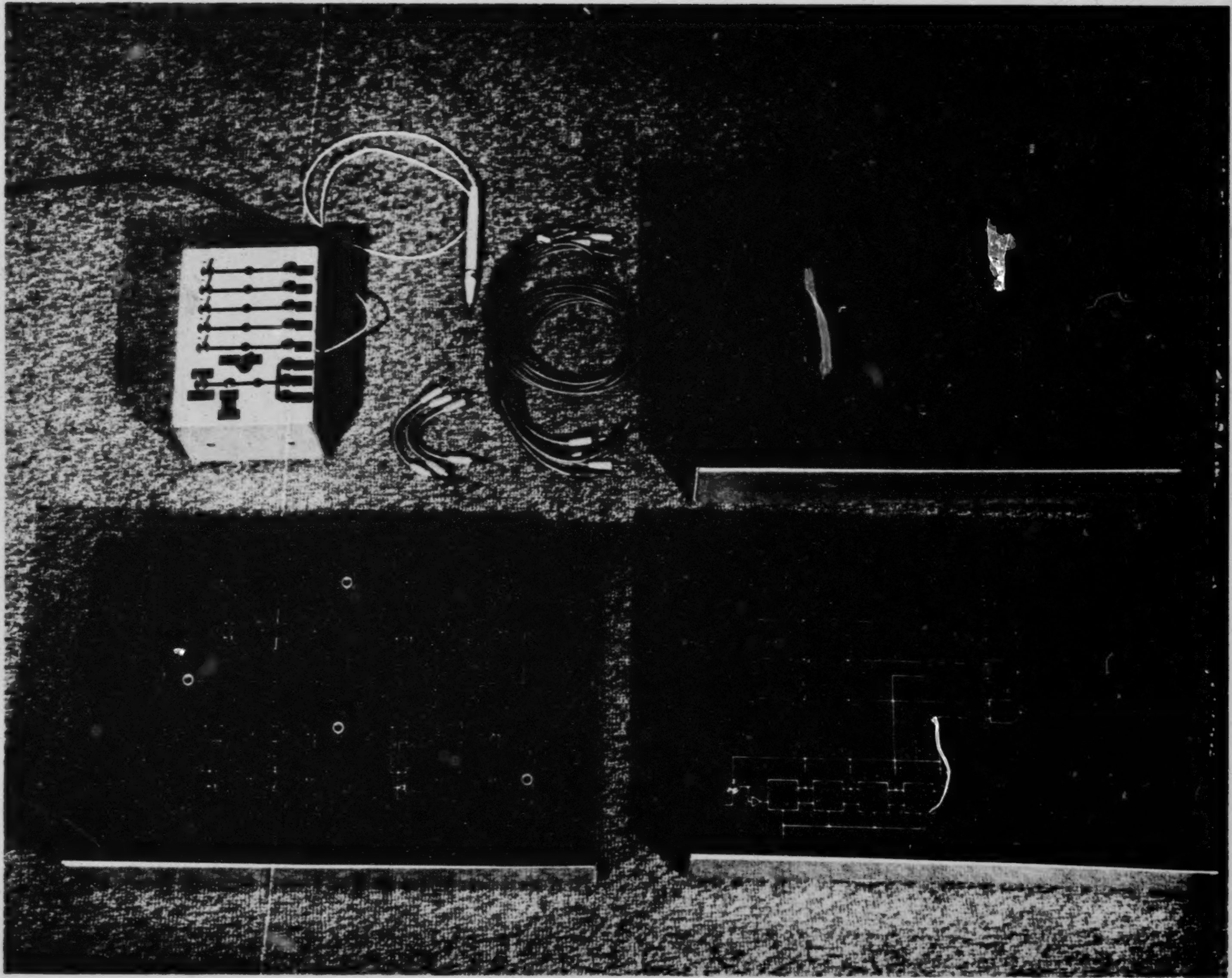


Figure 6. Skill test equipment.

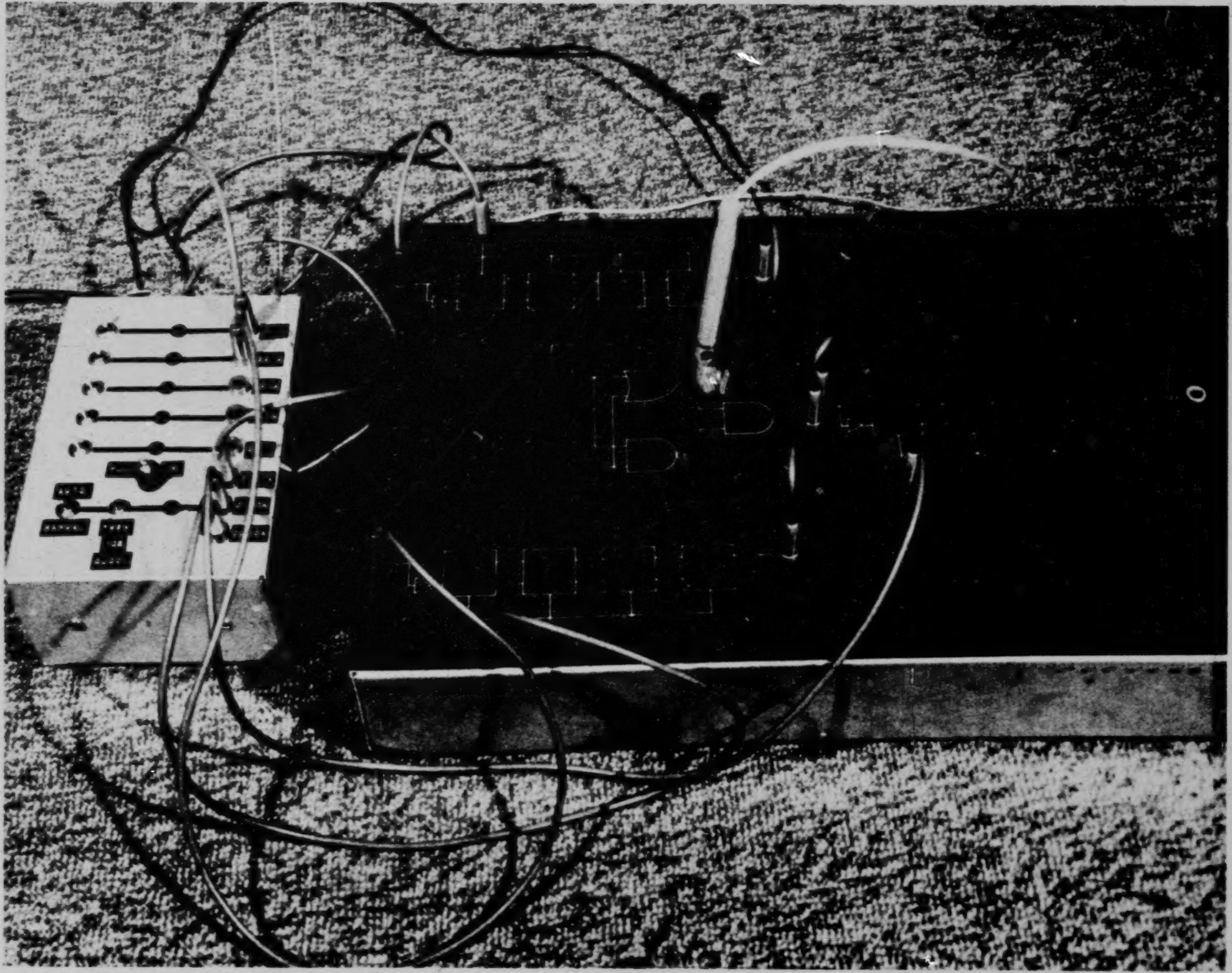


Figure 7. Connections between master box and half-adder circuit.

cases, the student was asked to bring the logic circuit into a certain specific state; this required the student to know how to make manipulations and to execute them. Performance measures for these tests included (1) the number of errors made before completing a specific problem and (2) the total time to correctly complete the problem. Only one fault was introduced into a circuit for each troubleshooting problem. Several different faults were used to create several problems for each of the three circuits. There were 14 problems in all.

Two months after completion of the course, a second Skill Test was given to measure retention. The second Skill Test used the same three circuits as did the first; however, different faults were introduced into each circuit to create different problems. This was necessary because of our concern that the students might remember the correct responses to the first set of problems. Because two forms of the Skill Test were constructed and administered, it was not possible to compare performance on individual items of the short-term and long-term skill tests. However, we did not want to lose entirely the capability for such a comparison; therefore, we embedded three problems from the first Skill Test into the set of problems for the second Skill Test. Students taking the second Skill Test did not appear to realize that three of the problems were the same as three problems in the first Skill Test.

Because our course did not include electronic theory, we could not test students directly on the "integrated chips" and electronic circuits which underlie digital logic circuits. Therefore, our test circuits were constructed so that students did not manipulate them at the electronic level, but rather at the digital logic level, where symbols were used to replace the actual integrated circuits or chips. We pre-wired the electronic circuits to appropriate connection points with the symbols. This made it relatively difficult for students to make wiring errors that would harm themselves or the circuits.

It should be noted, however, that during the test the students were really troubleshooting actual logic circuits; the only departure from reality was that they did not concern themselves with "ground and V_{cc}" connections between the integrated circuits and the power supply. Also, because they were using symbols, the students did not have to trace connections by identifying pins on integrated circuit chips. Our purpose was not to test them on circuit tracing, which would have necessitated a considerable expansion of the electronic aspect of the course. It also would have required a good deal more time in the performance test sessions and a significant increase in the expenditure of funds in exchange for a small increase in the face validity of the performance tests. Furthermore, Estelita (1972) has argued that digital logic is a viable discipline apart from electronic circuitry. He has stated that, "Standardizing...IC packages along logical function boundaries has in effect divorced the electrical circuit designer from the logic designer.... No specific technical knowledge is presupposed other than...switching algebra." Estelita goes on to describe the importance of "hands on" experience in learning digital logic. His comments reinforce the appropriateness of the course topic for the current study.

Some of the problems in the performance tests required that students simply recall material that they had learned in the course and apply the knowledge and skills for which they had received direct training to the solution of a given test problem. We called these problems "regular problems."

Other test problems required more than a simple regurgitation of knowledge and skills learned in the course; in these latter problems, students were confronted with circuits to which they had not been exposed before. These problems required students to synthesize the basic concepts and skills that had been trained previously into some larger concept of digital logic and to use this insight to attack unfamiliar problems. We called the latter problems "transfer problems." Because this latter sort of activity is an important part of applying course knowledge to operational problems, it was felt that this was a necessary aspect of comparing the two instructional approaches.

In a word, our intention in devising the Knowledge and Skill Tests, especially the skill tests, was to make evaluation and comparison of the two instructional approaches generalizable and meaningful to practical training situations. This logic also led us to include the longer-term retention tests in our comparisons of the two instructional approaches.

B. *Field Plan and Execution*

Figure 8 again shows the project plan; in this case the activities dealing with execution of the field study are highlighted. These activities included securing an appropriate source of subjects, selecting the subjects according to verbal aptitude and math/science aptitude, administering the two instructional curricula to two groups of subjects matched on aptitudes, and, finally, testing subjects upon completion of the course and after a long-term retention interval.

1. *Subjects*

Our first target population of potential subjects was the student body at Santa Barbara City College; these students represented a relatively wide range of verbal and math/science aptitudes, and they were in the appropriate age range for generalizing the results of this study to Navy trainees. After completing arrangements with officials of Santa Barbara City College to administer the two experimental curricula at the beginning of Fall Quarter, 1973, we discovered that fewer students would volunteer to participate in the experiment than school officials had originally predicted. Various inducements

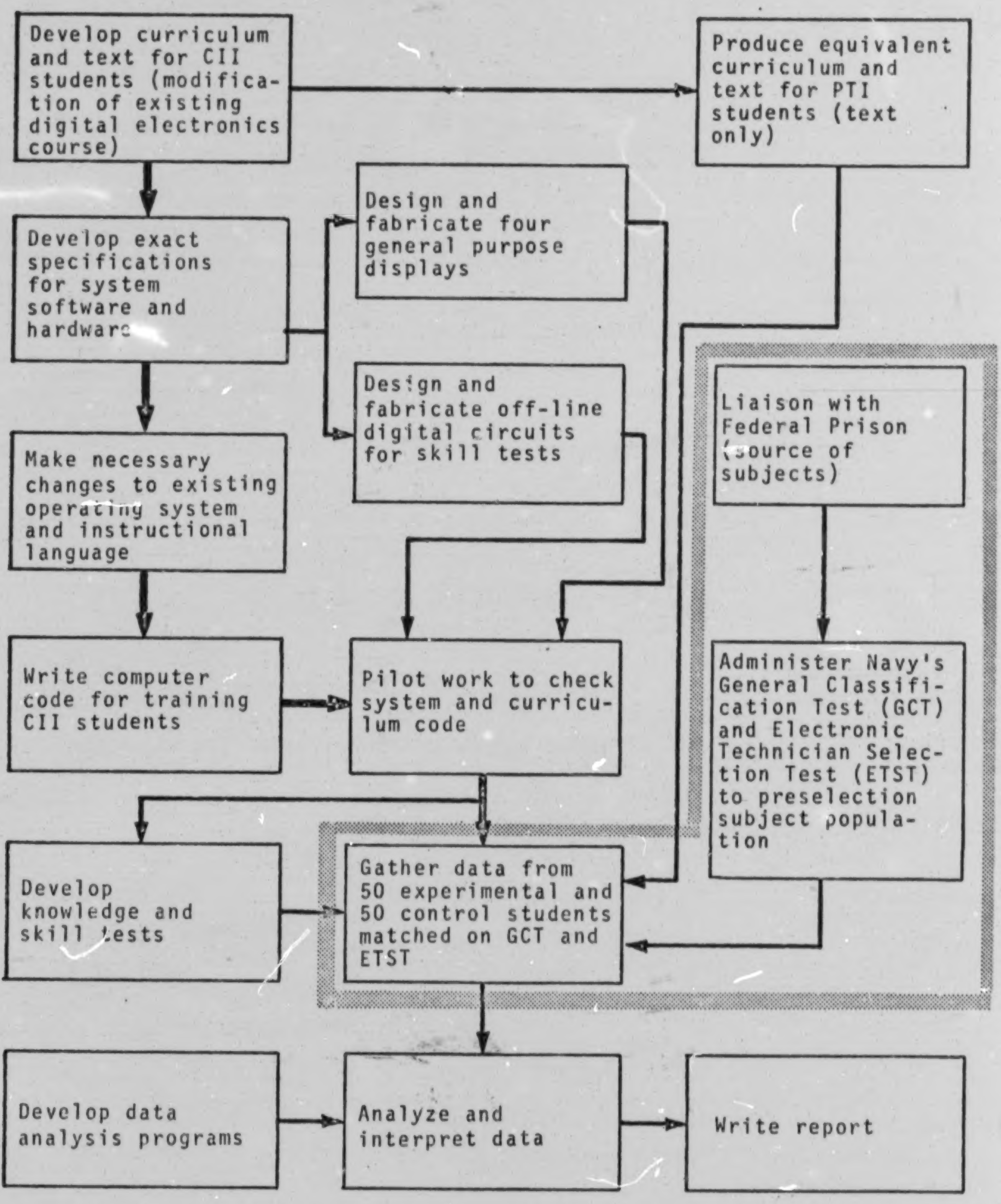

Develop curriculum and text for CII students (modification of existing digital electronics course)
Produce equivalent curriculum and text for PTI students (text only)
Develop exact specifications for system software and hardware
Design and fabricate four general purpose displays
Design and fabricate off-line digital circuits for skill tests
Make necessary changes to existing operating system and instructional language
Liaison with Federal Prison (source of subjects)
Write computer code for training CII students
Pilot work to check system and curriculum code
Administer Navy's General Classification Test (GCT) and Electronic Technician Selection Test (ETST) to preselection subject population
Develop knowledge and skill tests
Gather data from 50 experimental and 50 control students matched on GCT and ETST
Develop data analysis programs
Analyze and interpret data
Write report

Figure 8. Project plan: Execution of field study is highlighted.

were attempted in order to secure the required number of volunteers so that selection tests could be administered and 100 students with appropriate characteristics could be selected for participation in the courses. An adequate preselection population of volunteers could not be obtained; therefore, arrangements with Santa Barbara City College were canceled.

The next most accessible population of subjects with the appropriate aptitude and age characteristics resided at the Federal Correctional Institute at Lompoc, California, and at the California Men's Colony at San Luis Obispo, California. Liaison with these institutions, and the agencies which supervised them, proved to have favorable results in both cases. Because the population at the Federal Correctional Institution appeared to represent a broader range of verbal aptitude, these prisoners were chosen as subjects for the study.

About 200 inmates volunteered to participate in the study. Personnel who completed all aspects of the course received a $20.00 stipend and a certificate of course completion. The new, short form of the Navy's General Classification Test (GCT) and the Electronic Technician Selection Test (ETST) were administered to the volunteers to assess verbal aptitude and math/science aptitude, respectively.

A two-dimensional plot of the volunteers' scores on the GCT and ETST was made and pairs of nearly-coincident points on the plot were identified by inspection. Fifty such matched pairs were identified, and the members of a given pair were randomly assigned to the two experimental treatments.

A problem that confronted us in selecting subjects for this study was that of defining the lowest acceptable aptitude level for subjects. We did not want to expend time and funds unnecessarily to train and test personnel who clearly could not benefit from either of the experimental curricula. Still, we wanted to relate the effectiveness of each of the curricula to varying levels of aptitude, including the lowest level students who could be trained in the relatively sophisticated skills in our experimental course.

We discussed the matter with a senior staff member of the Personnel Measurement Research Department of the Navy Personnel Research and Development Center at San Diego; he felt that the nominal level of verbal aptitude for a Naval training course in logic and electronics should be about one standard deviation above the general population mean. He also felt that the lower limit in verbal aptitude for students who could benefit from such a course would be at about the population mean. These figures were informal estimates and are not to be construed as official Navy opinion. However, we used these estimates as guidelines to help reduce study costs by eliminating unnecessary exploration on the lower end of the verbal aptitude scale.

We used a GCT score of 15 as the lower cutoff point on verbal aptitude. This is equivalent to 47 on the Navy Standard and it is approximately one-third of a standard deviation below the Navy Mean of 50. We felt this would ensure that our sample would include subjects in the lowest range of verbal aptitudes who could reasonably be expected to derive some benefit from the experimental training courses.

We employed no cutoff score for the ETST. We wanted to include students representing the entire range of math/science aptitudes, given that they met the minimum reasonable requirements for verbal aptitude.

Some mention should be made of the background of the subject population. Since the subjects were prisoners at a Federal Correctional Institute (FCI), this may raise some questions in the reader's mind about the generalizability of the results to other populations. We did not feel that this was a particular problem in this study because of the general characteristics of the inmates, some of which will be described.

The nominal age range for inmates at the Lompoc FCI is 18 to 26 years. Their criminal background was varied: a large proportion had violated Federal drug laws, another large proportion included Vietnam war dissenters, still another fairly large proportion included convicted bank robbers, and a fourth group included Indians who had committed crimes on Federal Reservations. Except for the last group, the inmates appeared to represent a fairly broad range of socioeconomic backgrounds. The entire range of educational class levels was represented, including adequate representation of the upper educational levels, especially by the war dissenters. Also, a selection factor was operating because we dealt only with inmates who volunteered; those who participated in the study demonstrated relatively high motivation, intelligence, and interest in the subject matter. In fact, HFR staff members involved in training or testing the subjects felt that, in most cases, they were dealing with the sorts of people who might have been volunteers from the original target population at Santa Barbara City College.

In short, the students at the prison behaved very much as students anywhere. The main differences between the prison environment and a "normal" environment were (1) the restrictive atmosphere of the institution itself and (2) an undercurrent of verbal hostility directed toward the institution. These two factors might well exist to some degree in a training course at a military institution. We could find nothing in the range of aptitudes, or in the biographical material that we collected for this population, that argued against generalizing the results of this study to trainees in a skill-oriented curriculum at a military institution or a vocational school.

2. *Training and Testing*

Students were trained in groups of 8: 4 PTI students and 4 CII students were supervised by one proctor who was knowledgeable in the course subject, the experimental design, and operation of the CII software and hardware. Later, performance tests were administered by a different proctor who had no knowledge of a student's aptitudes or instructional treatment.

Figure 9 shows the layout of the classroom used for training. A visual barrier provided nominal isolation of the PTI students from the CII students; however, the proctor was equally accessible to both groups. The proctor provided assistance and explanations whenever requested and he also operated the computer system for the CII terminals. The computer and basic peripherals were located in a separate room. The computer required proctor attention only at the beginning of a session before students began working at their terminals, after a session when students had left, and on infrequent occasions during a session when trouble developed with the CII system. Otherwise, the proctor was always available to assist the students. He kept a covert log of the amount of time spent assisting each student and the amount of time required by each to complete the course.

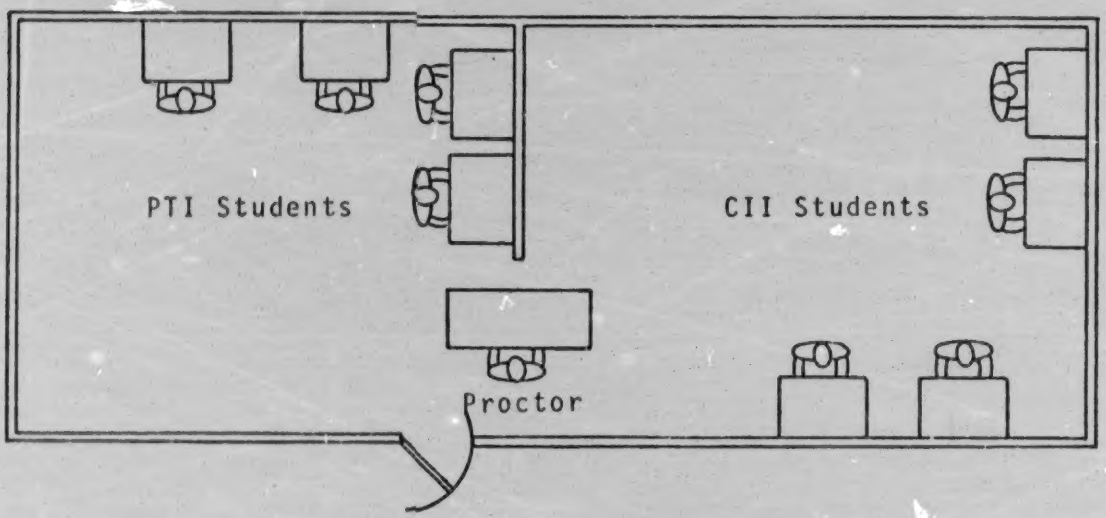


Figure 9. Layout of classroom.

Students were allowed as much time as they wished to complete the training phase of the experiment. All of them, except two at the lowest aptitude levels, completed the course within the 15 hours originally allotted. The two slow students finished after an additional two hours on the Monday following the regular 5-day series of 3-hour training sessions. Students who finished early were told that they might spend time reviewing the material; however, we did not emphasize a need to spend a great deal of time in review but allowed them to end the training phase as soon as they felt that they understood the material.

The test proctor administered the short-term knowledge and performance tests to each student during the week that followed his training sessions. This was done in a different room so that a new group of students could begin training. The test proctor administered the long-term retention tests to each student eight weeks after he had completed the short-term retention tests.

Approximately five months were required to complete the training and testing of 106 students. For various reasons, several students did not complete all aspects of the training and testing program. Complete data were gathered on 42 pairs of students matched on the GCT and ETST. Only the data on these 84 students, 42 in the CII treatment and 42 in the PTI treatment, were used in subsequent data analyses.

V. RESULTS AND ANALYSES

The independent variables in this study were verbal aptitude (score on GCT), math/science aptitude (score on ETST), and training treatment (PTI vs. CII). The dependent variables were all the measures of knowledge and skill taken at short-term and long-term retention intervals, plus two general measures of student behavior during training. The following is a list of all the dependent variables:

Measures of Classroom Behavior

1. Time To Complete Training Course
2. Number of Interactions with Proctor During Training

Measures of Knowledge

3. Pre-Course Knowledge Test
4. Short-Term Knowledge Test
5. Short-Term Knowledge Gain (4-3)
6. Long-Term Knowledge Test
7. Long-Term Knowledge Gain (6-3)
8. Forgetting (4-6)

Measures of Short-Term Skill

9. Time To Complete each of 14 Problems
10. Total Time To Complete the Skill Test
11. Number of Timed-Out Problems (where arbitrary time limit was exceeded)
12. Number of Errors on Regular Problems
13. Number of Errors on Transfer Problems
14. Total Number of Errors on the Skill Test

Measures of Long-Term Skill

15. Time To Complete each of 14 Problems

16. Total Time To Complete the Skill Test

17. Number of Timed-Out Problems

18. Number of Errors on Regular Problems

19. Number of Errors on Transfer Problems

20. Total Number of Errors on Skill Test

Various combinations of the independent and dependent variables were used in the three phases of analysis discussed below. In the first phase, graphs were used to relate a sample of dependent measures to the independent variables. In the second phase, the entire set of dependent measures, including item scores on the skill tests, was subjected to a series of discriminant analyses. The final phase of the data analysis was a series of univariate tests to test the significance of aptitude and training treatment differences with respect to single measures.

A. *Preliminary Data Analysis*

Simple graphs were constructed to show the relationships between the aptitude scores and two short-term and long-term retention measures. One of the measures was the Knowledge Test score; the other was Total Time to Complete the Skill Test. The latter measure of skill was used in the preliminary analysis, rather than an error measure, because most of the students completed all of the problems with relatively few errors. Time to Complete the Test appeared to discriminate among students better than any of the error measures. Error measures were included in later analyses, however.

Each of the following graphs contains a curve for the CII treatment and a curve for the PTI treatment. The data were smoothed by grouping students on the independent variable and deriving group means for the dependent variables. Four figures that deal with the Knowledge Test measure are presented on the next two facing pages for convenient comparisons. Correlations among the variables are presented in Table 2.

Figure 10 shows the relationship between scores on the Short-Term Knowledge Test and scores on the GCT (verbal aptitude) for the PTI and CII training treatments. This figure shows the expected relationship between achievement in a training course as measured by a written examination, and verbal aptitude, *viz*, the high aptitude students obtained higher scores on the Knowledge Test. A score of 18 on the GCT is the mean for this test, or the equivalent of a Stanford-Binet IQ of 100. Figure 10 shows no systematic mean differences in Knowledge Test scores between the CII group and the PTI group. The correlation coefficients between GCT and Knowledge Test scores were .59 and .65 for the CII and PTI groups, respectively.

Figure 11, like Figure 10, shows performance on the Long-Term Knowledge Test to be positively related to score on the GCT; again there were no systematic differences between the CII and PTI groups. Correlations between verbal aptitude and long-term knowledge were .57 and .47 for the CII and PTI groups, respectively.

Figures 12 and 13 show the corresponding results using scores on the ETST (math/science aptitude) as the independent variable. It should be mentioned that scores on the GCT and the ETST were moderately correlated; the Pearson product-moment correlations between GCT and ETST scores for our CII and PTI groups were .66 and .68, respectively. Data on the population of Navy enlistees who have taken the GCT and ETST yield a correlation of about .63.

Figure 12 shows a strong relationship between performance on the Short-Term Knowledge Test and score on the ETST; students

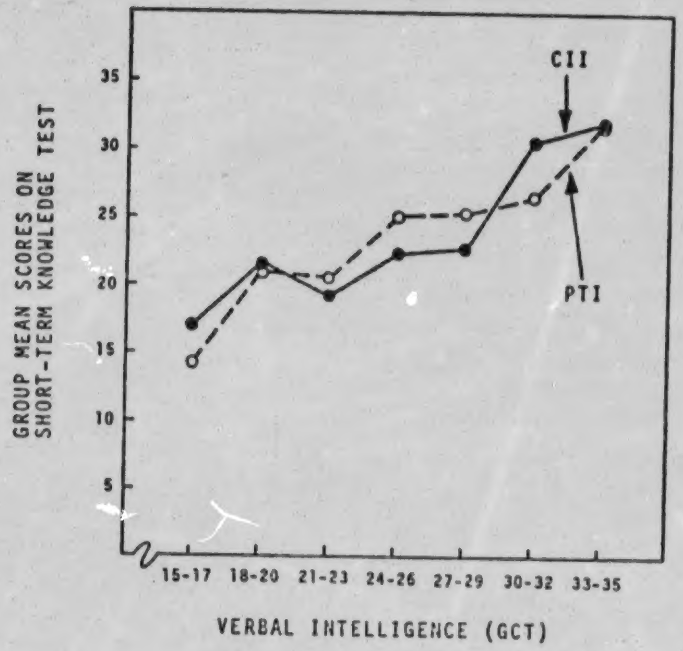


Figure 10. Short-term knowledge as a function of verbal aptitude and training treatment.

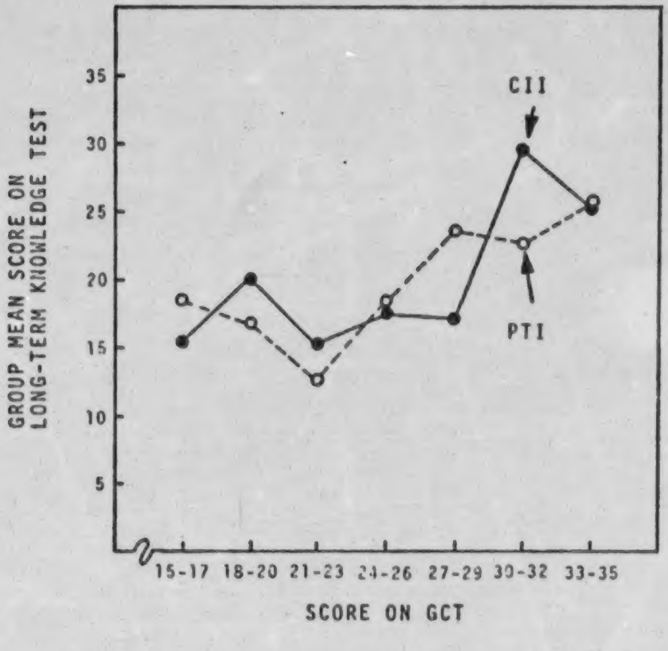


Figure 11. Long-term knowledge as a function of verbal aptitude and training treatment.

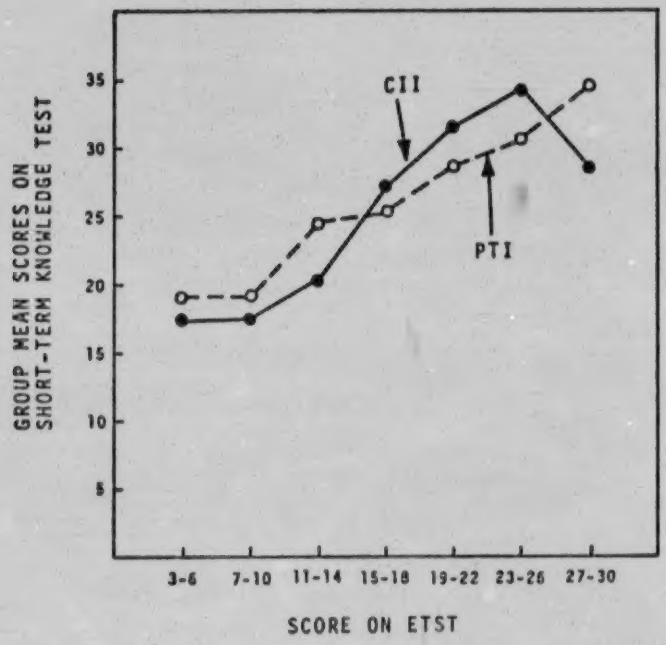


Figure 12. Short-term knowledge as a function of math/science aptitude and training treatment.

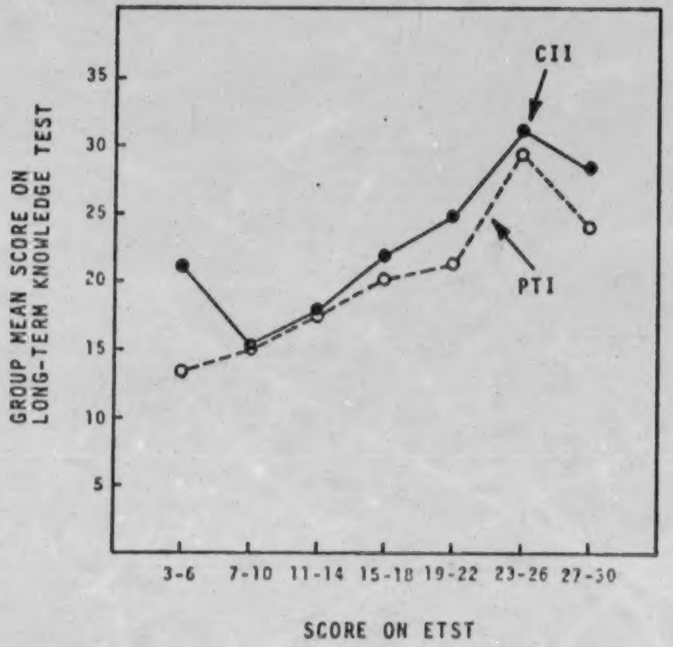


Figure 13. Long-term knowledge as a function of math/science aptitude and training treatment.

TABLE 2

INTERCORRELATIONS AMONG APTITUDE SCORES, SCORES ON THE KNOWLEDGE TESTS, AND TIME TO COMPLETE THE SKILL TESTS

	GCT	ETST	SHORT-TERM KNOWLEDGE	LONG-TERM KNOWLEDGE	SHORT-TERM SKILL	TRAINING GROUP
ETST	.66					CII
	.68					*PTI*
Short-Term Knowledge	.59	.74				CII
	.65	*.67*				*PTI*
Long-Term Knowledge	.57	.74	.75			CII
	.47	*.44*	*.70*			*PTI*
Short-Term Skill (time taken)	-.52	-.68	-.73	-.68		CII
	-.28	*-.38*	*-.68*	*-.61*		*PTI*
Long-Term Skill (time taken)	-.48	-.70	-.74	-.69	.86	CII
	-.30	*-.34*	*-.62*	*-.64*	*.73*	*PTI*

with higher aptitudes scored better. There were no systematic mean differences between the CII and PTI groups. The correlations between ETST and Short-Term Knowledge Test scores for the CII and PTI groups were .74 and .67, respectively.

Figure 13 shows score on the Long-Term Knowledge Test generally to be an increasing function of score on the ETST; there were curious, inexplicable reversals for the highest aptitude groups in both the CII and PTI treatments, and for the lowest aptitude group in the CII treatment. The number of students in these groups at the extreme ends of the aptitude scale was small. Therefore, these reversals probably do not represent reliable phenomena. There were no significant mean differences between the CII and PTI groups, as tested by analysis of variance discussed later. The correlations between

ETST and the Long-Term Knowledge Test were .74 and .44 for the CII and PTI groups, respectively. This indicates that long-term knowledge was less predictable from math/science scores for the PTI group than for the CII group.

The next four figures deal with the Skill Test measure.

Figure 14 shows the relationship between time required to complete the Short-Term Skill Test and scores on the GCT for the two training treatments. Time required to complete the performance test was a decreasing function of verbal aptitude; the brighter students finished the test in a shorter time. There appeared to be no systematic mean differences between the PTI and CII groups. However, there was a difference in the correlations between GCT and Short-Term Skill Test scores for the two groups. The correlations were -.52 and -.28 for the CII and PTI groups, respectively. Again, aptitude was a less potent predictor of performance for the PTI group than for the CII group.

Figure 15 shows that time taken to complete the Long-Term Skill Test was a decreasing function of score on the GCT; this graph shows a slight superiority for the PTI students, especially those of lower verbal aptitude. As discussed later, this result was not statistically significant. The correlations between GCT and Long-Term Skill scores were -.48 and -.30 for the CII and PTI groups, respectively.

Comparison of Figures 14 and 15 reveals a perceptible change in the slopes of the curves over the long-term retention interval. The relatively flat curves in Figure 15 suggest that the lower verbal aptitude students are "catching up" to the higher aptitude students in skill performance at the long-term test point. However, an analysis of variance, discussed later under *Univariate Analyses*, showed the high aptitude students to continue to perform significantly better than the low aptitude students at the long-term test point of skill.

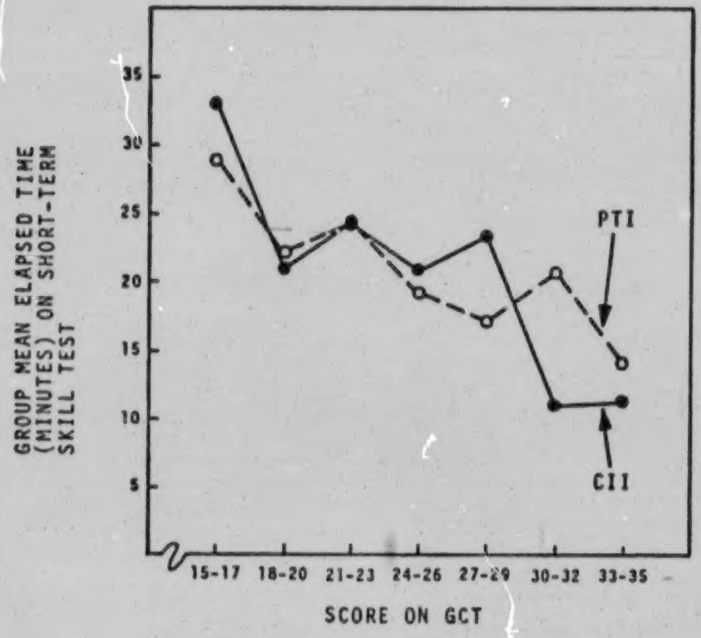


Figure 14. Short-term troubleshooting performance as a function of verbal aptitude and training treatment.

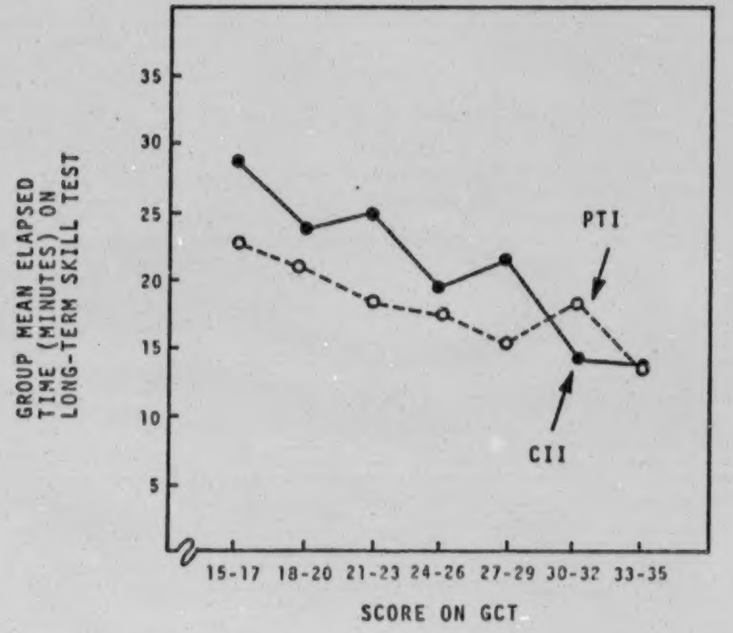


Figure 15. Long-term troubleshooting performance as a function of verbal aptitude and training treatment.

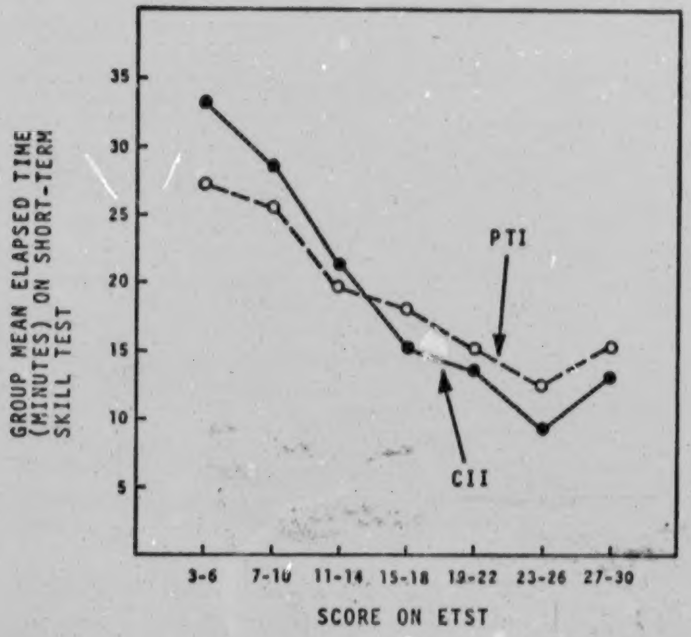


Figure 16. Short-term troubleshooting performance as a function of math/science aptitude and training treatment.

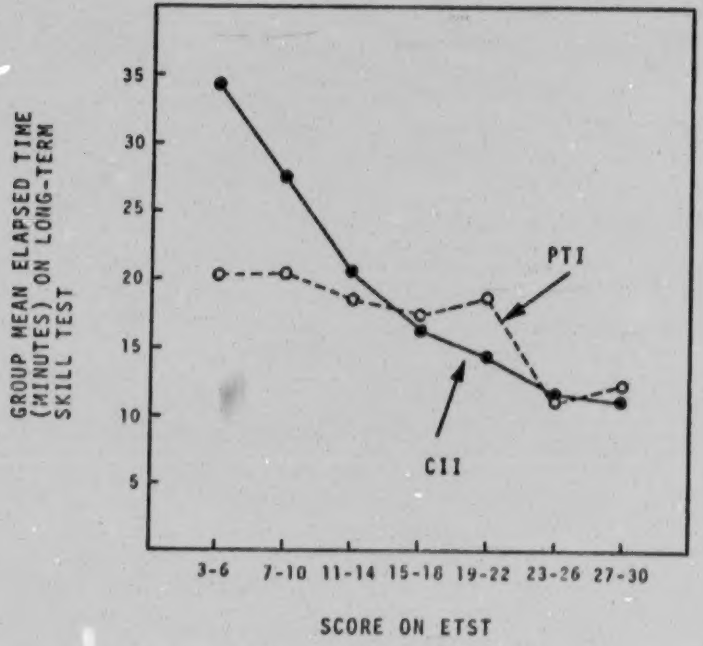


Figure 17. Long-term troubleshooting performance as a function of math/science aptitude and training treatment.

Figures 16 and 17 show the corresponding results using score on the ETST as the independent variable.

Figure 16 shows that time required to perform the Short-Term Skill Test decreased with increasing aptitude as measured by the ETST. The two curves cross over and suggest an aptitude-treatment interaction; however, statistical tests did not prove this interaction to be significant. Correlations between ETST and Short-Term Skill Test scores were -.68 and -.38 for the CII and PTI groups, respectively. Again, tested performance was less predictable from math/science aptitude score for the PTI group than for the CII group.

Figure 17 shows that time required to complete the Long-Term Skill Test was also a decreasing function of math/science aptitude; furthermore, the low aptitude students in the PTI group completed the skill test in significantly less time than the low aptitude students in the CII group. The analysis to test this result is discussed later. Correlations between long-term skill and math/science aptitude were -.70 and -.34 for the CII and PTI groups, respectively. Once again, tested performance was less predictable from ETST scores for the PTI group than for the CII group.

In summary, the curves in Figure 10 through 17 showed the logically expected positive relationship between performance and aptitude. There was also evidence of a possible superiority of the low aptitude students in the PTI group over the low aptitude students in the CII group on the criterion of long-term skill performance.

It is interesting to note the moderately high correlations among short- and long-term knowledge and skill tests in Table 2. Not only are the correlations high between short- and long-term tests of a given kind, but the correlations between kinds of tests are also high. In a sense, the validity of the knowledge test is supported by its high correlations with skill measures of high face validity.

The next step in the analysis of the data employed a multivariate technique to examine the relationships between the independent variables and all the dependent variables.

B. *Multivariate Analysis*

A very powerful multivariate technique exists for conveniently investigating a large number of measures taken on individuals that comprise different subpopulations. (The subpopulations in the present experiment may be defined as the individuals that comprised different aptitude levels in the different instructional treatments.) We felt that this technique would help us answer the following question: "Given all the methods that we used to measure performance, were there any real differences between the students from the PTI course and those from the CII course?" Furthermore: "If there were performance differences, how were they related to different aptitude levels?"

The multivariate technique that we used to address these questions is discriminant analysis. Briefly, this technique is used when a variety of measures is taken on several predetermined classes of things. The object of the analysis is to determine whether or not the *classes are different from one another* with respect to the measures. Discriminant analysis is different from factor analysis, another common multivariate technique, where a variety of measures is taken upon one population of things with the intention of discovering which *subsets of similar measures* can be identified. Detailed discussions of discriminant analysis may be found in Rulon (1951A and 1951B), Tiedeman (1951), Rao (1952), Cooley and Lohnes (1962), and Anderson (1958).

We performed four separate discriminant analyses: The first included all of the dependent variables listed on pages 59 and 60 *except* the time to complete each individual item in the Skill Tests, and the error scores for the breakdown of "Regular" and "Transfer" items in the Skill Tests. Size limits in the discriminant analysis program prevented us from using all the dependent measures in the first, general analysis. The second discriminant analysis focused on the six measures related to the paper-and-pencil knowledge tests. The third analysis focused on all the measures of short-term skill; the fourth, on all the measures of long-term skill.

All of these analyses used the same two independent variables of instructional treatment (CII versus PTI) and score on the ETST (low versus high). Because discriminant analysis is rather expensive in terms of computer time, we could not thoroughly explore *all* of the dependent variables relative to both of the aptitude variables in this phase of analysis. Since the preliminary analysis showed possible significant relationships between aptitude and the dependent measure in two cases for the ETST and in only one case for the GCT, we chose to use the ETST scores as the important aptitude variable for discriminant analyses.

The computer program to perform the discriminant analysis was Cooley and Lohne's Multiple Discriminant Analysis Program, adapted to run on the General Electric Mark III Time Sharing System. Before the discriminant analyses were run, several small programs were used to pre-process the data into manageable form and to sort students into groups according to the independent variables of interest. We will not dwell on the details of these programs; however, we will describe the general algorithm for sorting students and their data.

Recall that pairs of students matched on GCT and ETST scores were identified and members of each pair were randomly distributed to the two treatment conditions. In sorting the students for the discriminant analyses, we again dealt with the matched pairs in the following way: For each matched pair, the sum of their scores on the ETST was derived and those sums were ranked. We defined the 16 highest-ranking matched pairs (this comprised about 40% of the experimental sample) to be the "high aptitude" students, and the 16 lowest-ranking matched pairs to be the "low aptitude" students. Because each matched pair contained one CII student and one PTI student, we had defined four subpopulations, or classes, *viz*, the high aptitude CII students, low aptitude CII students, high aptitude PTI students, and finally, low aptitude PTI students. We called these the HICOMP, LOCOMP, HITEXT, and LOTEXT groups, respectively.

These four groups were the "predetermined classes of things" which the discriminant analysis program tried to discriminate, upon the basis of the dependent variables. To the extent that certain measures were differentially related to aptitude and treatment levels, the discriminant analyses would "separate" the four groups.

1. *General Discriminant Analysis*

The first analysis used 14 general performance measures from the list on pages 59 and 60. Item latency scores and errors for Regular and Transfer problems were excluded. The 14 measures of performance form the dimensions of a multivariate space. To the extent that the individuals in a given group, say LOTEXT, perform differently from the individuals in the other groups, the swarm of points representing the individuals in LOTEXT will occupy a different portion of this 14-space than will points representing the other individuals.

We can reduce this 14-space to something that is conceptually manageable through discriminant analysis on a computer. The computer program finds a function that will maximize the separation between groups by deriving a set of linear weights for the n variables that will minimize the ratio of within-group variance to between-group variance. In our geometric model, this function would be represented by a line in 14-space.

If one projected the points that represent individuals in 14-space onto this line, the points for LOTEXT would (hopefully) cluster together and be separated from the points for the other groups. The points for LOTEXT could be described by their mean and standard deviation with respect to this function.

Having calculated the discriminant function (or, line in n-space) that best separates the groups, the step-wise multiple discriminant program then finds the next best discriminant function for separating the groups. In our geometric model, this second line, along with the first, would describe a plane in 14-space. Again, the points in 14-space could be projected onto the plane, and we would expect that this additional discriminating power would reveal a further separation of the projected points for LOTEXT from the projected points for the other groups. The points for LOTEXT, when projected upon this plane, could be described by their centroid and one standard deviation centour. (A centour is a con*tour* that delimits some per*cent* of a multidimensional swarm or cloud of points, and has as its centroid the centroid of the entire swarm. A one standard deviation, or one-sigma, centour would contain 68% of the points in a multidimensional swarm.)

Figure 18 shows the four group centroids and one-sigma centours on the plane defined by the first two discriminant functions. The first discriminant function, represented by the abscissa, accounted for 67.9% of the discriminating power; the second discriminant function, represented by the ordinate, accounted for 25.8% of the discriminating power. The third discriminant function accounted for only 4.64% of the discriminating power, and therefore no attempt was made to graph it on a third axis.

Inspection of Figure 18 shows that the first discriminant function primarily discriminated between the low and high aptitude students. None of the centours for the low aptitude students intersect with the centours for the high aptitude students;

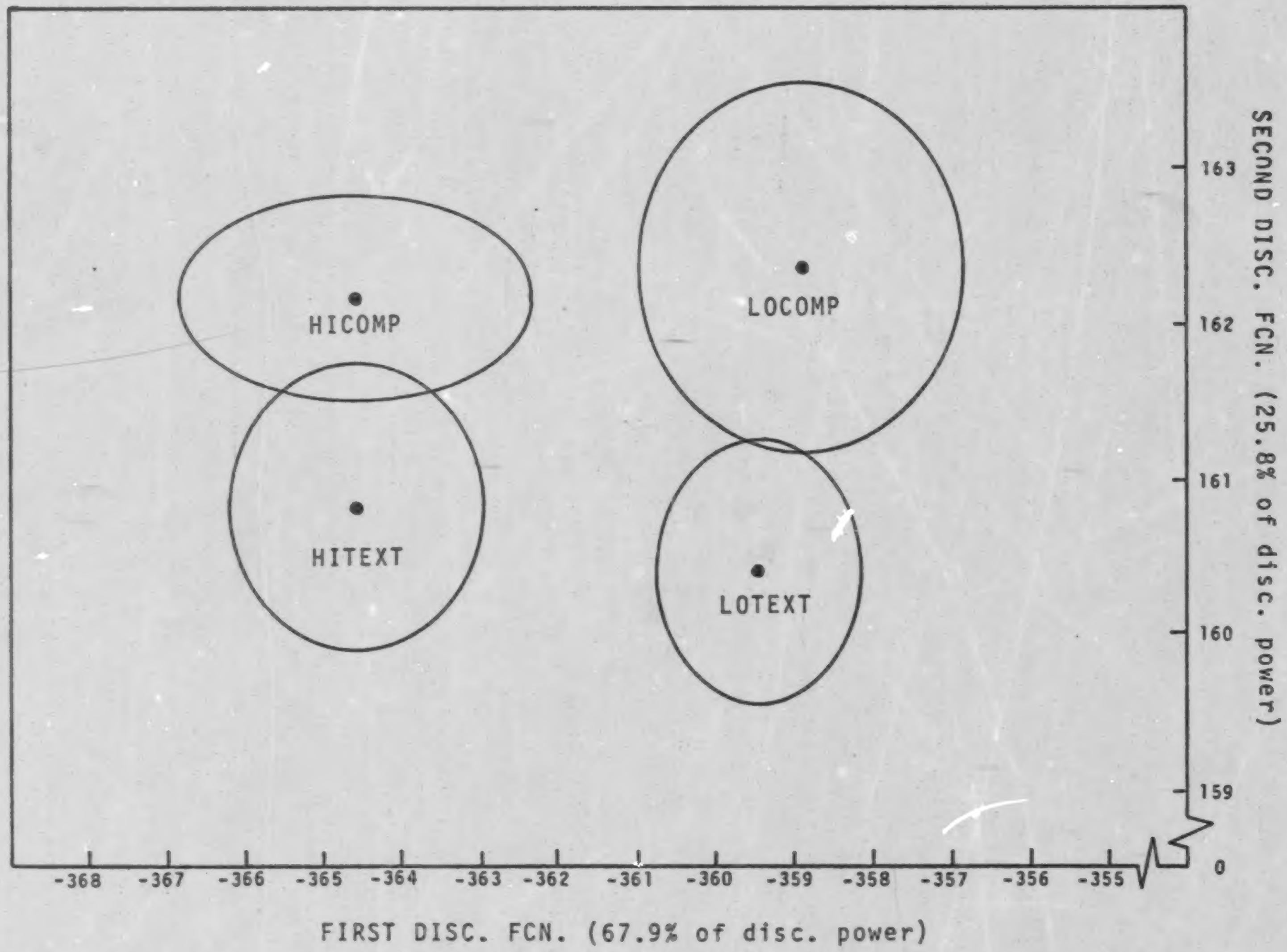


Figure 18. Centroids and 1-sigma centours for 4 groups in first 2 dimensions of reduced discriminant space for summary analysis.

this is not a startling result, for our earlier graphs showed what common sense would predict--the high aptitude students performed better than the low aptitude students. The second discriminant function achieved separation between the PTI students and the CII students. However, there is some overlap between the students for the two treatment groups as evidenced by the intersection of the one-sigma contours at both aptitude levels.

Rao's F approximation of Wilke's lambda criterion (Cooley and Lohnes) showed that the general discrimination among the four groups was significant beyond the .01 level. Basically, this test compares the generalized within-group variance with the overall variance.

The positive results of the general discriminant analysis indicated the existence of some potent relationships between the independent and dependent variables. The next step was to use different sets of measures in subsequent discriminant analyses to discover which of the dependent variables were importantly related to math/science aptitude and training treatment.

2. *Discriminant Analysis Using Knowledge Measures*

The six measures of knowledge listed on page 59 were used in the second discriminant analysis. Figure 19 shows the results. The first discriminant function accounted for nearly 90% of the discriminating power of this analysis and it primarily separated the high and low aptitude students. The second function shows some separation of the treatment conditions at the low aptitude level, but this discriminant function only accounted for 7.1% of the power in this analysis.

Rao's F approximation was significant beyond the .01 level. It appears that the knowledge measure primarily discriminated aptitude differences. There is weak evidence for superior performance of HICOMP over HITEXT, because the HITEXT

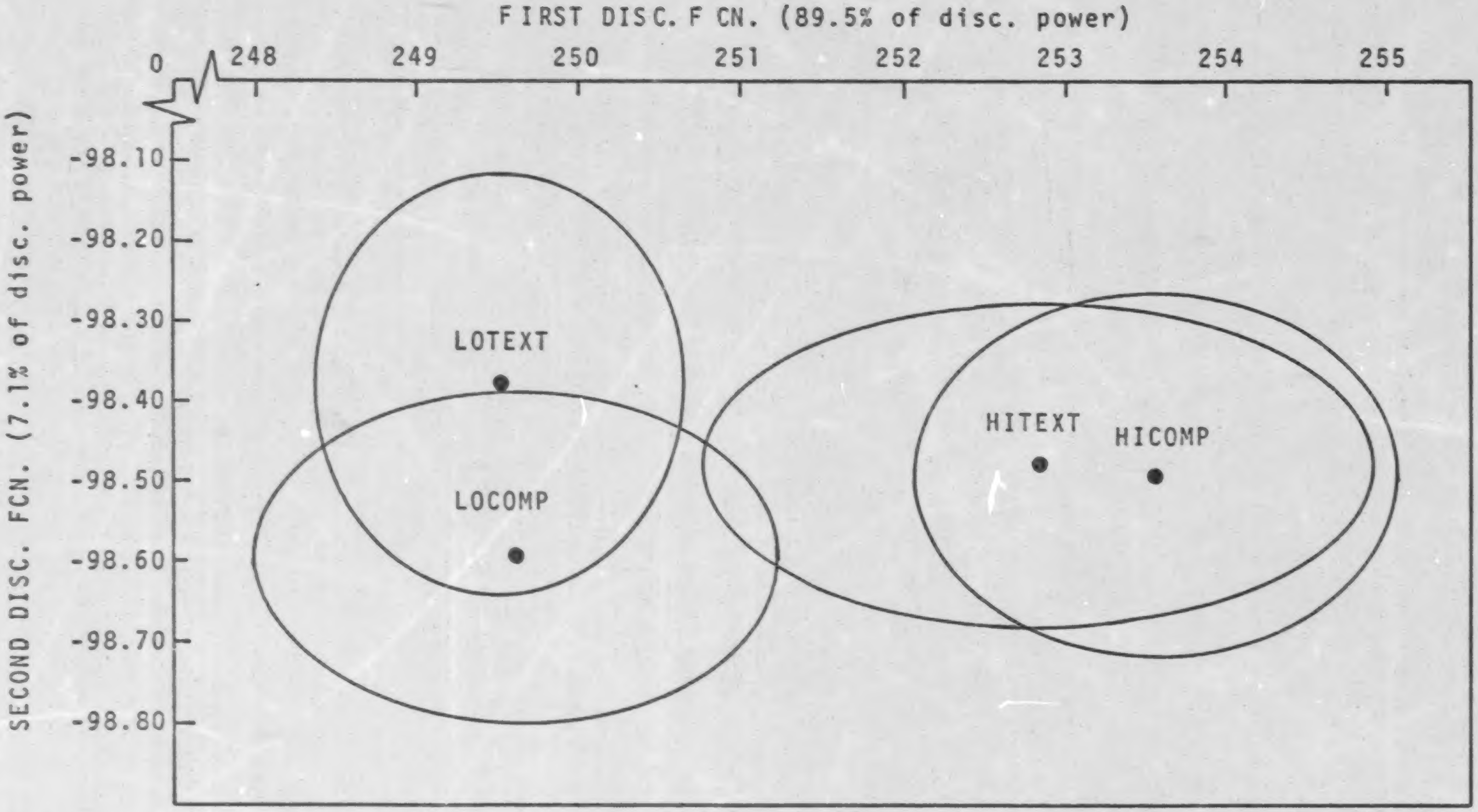


Figure 19. Centroids and 1-sigma centours for 4 groups in first 2 dimensions of reduced space for knowledge measures.

centroid is closer to the centroids for the low aptitude groups and HITEXT's large variance on the first function places the bulk of its swarm toward the low aptitude swarms. It should be noted that the directions and magnitudes of the scales for the discriminant functions do *not* have simple relationships with "goodness" of performance; they are a result of a complex series of matrix algebra manipulations. The figures can be effectively used to discover whether or not groups are similar to, or different from, one another with respect to a given *set* of measures. In Figure 19, the HITEXT students were more like the low aptitude students on the knowledge measures than were the HICOMP students.

3. *Discriminant Analysis Using Short-Term Skill Measures*

All the measures listed on page 59 which dealt with performance on the Short-Term Skill Test were used in the third discriminant analysis. Figure 20 shows the results of the third discriminant analysis. This figure is a little more complex than the prior two because it shows the third discriminant function, which accounted for a sizable amount of the power in this analysis. We have drawn the simple ellipses for the first two dimensions and then added vectors to show where the centroids for each group should be placed along the third dimension. We have not attempted to illustrate the dispersion of the swarms in the third dimension; one may expect, from the rather low discriminating power of the third function, large dispersions relative to the differences in centroids.

Again, the first, and most powerful, discriminant function primarily discriminated between aptitude levels. The second function showed good discrimination between training treatments for the low aptitude students and some discrimination between treatments for the high aptitude students. The third function showed discrimination between LOTEXT and LOCOMP with respect to their centroids.

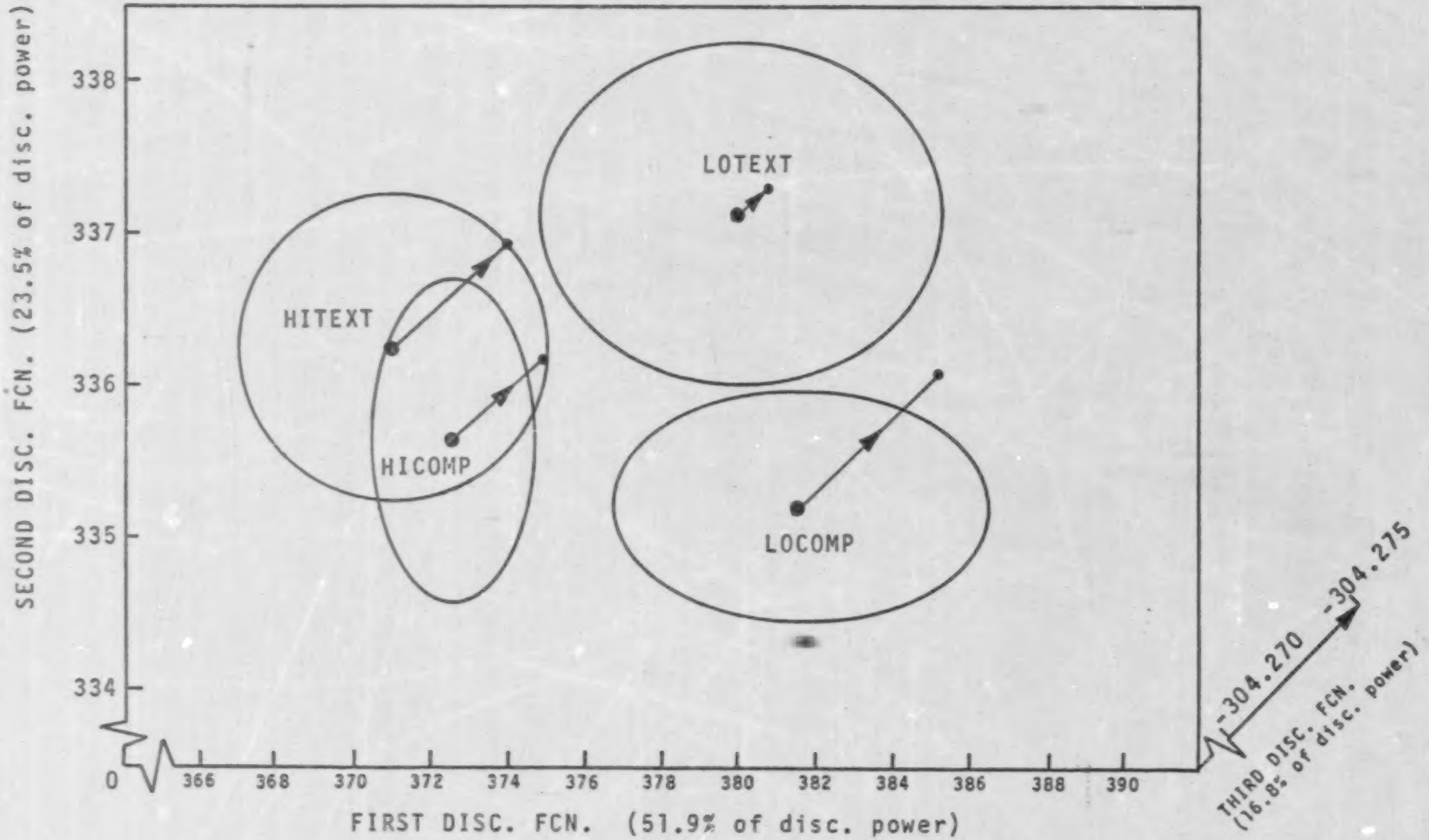


Figure 20. Centroids and 1-sigma centours for 4 groups in 3 dimensions of reduced discriminant space for Short-Term Skill Test measures.

Rao's F-approximation was significant beyond the .01 level. In general, this analysis showed that the high aptitude students were fairly similar to one another on the Short-Term Skill Test measures, regardless of training treatment, and the low aptitude students showed differences related to training treatment. Low aptitude students performed differently from high aptitude students.

4. *Discriminant Analysis Using Long-Term Skill Measures*

The measures of long-term skill performance listed on page 60 were used in the fourth discriminant analysis. Figure 21 shows the results plotted in three dimensions. It appears that there was little to distinguish the long-term skill performance of high aptitude students in the two training treatments. In this figure, the centroids for HICOMP and HITEXT lie in separate planes defined by the third discriminant function. However, this function accounts for only 11.1% of the discriminating power; i.e., the separation of centroids is small relative to the variance. In essence, the high aptitude students were indistinguishable.

The low aptitude students in the two training groups were well separated by the second discriminant function and, to a lesser extent, by the first discriminant function. Their one-sigma contours showed little overlap.

Rao's F-approximation was significant beyond the .01 level. We might conclude from this analysis that with respect to the long-term retention test of skills, which is probably the criterion of highest operational importance, (1) high aptitude students performed differently from low aptitude students, (2) training treatment did not differentially influence the performance of high aptitude students, and (3) training treatment did influence the performance of low aptitude students.

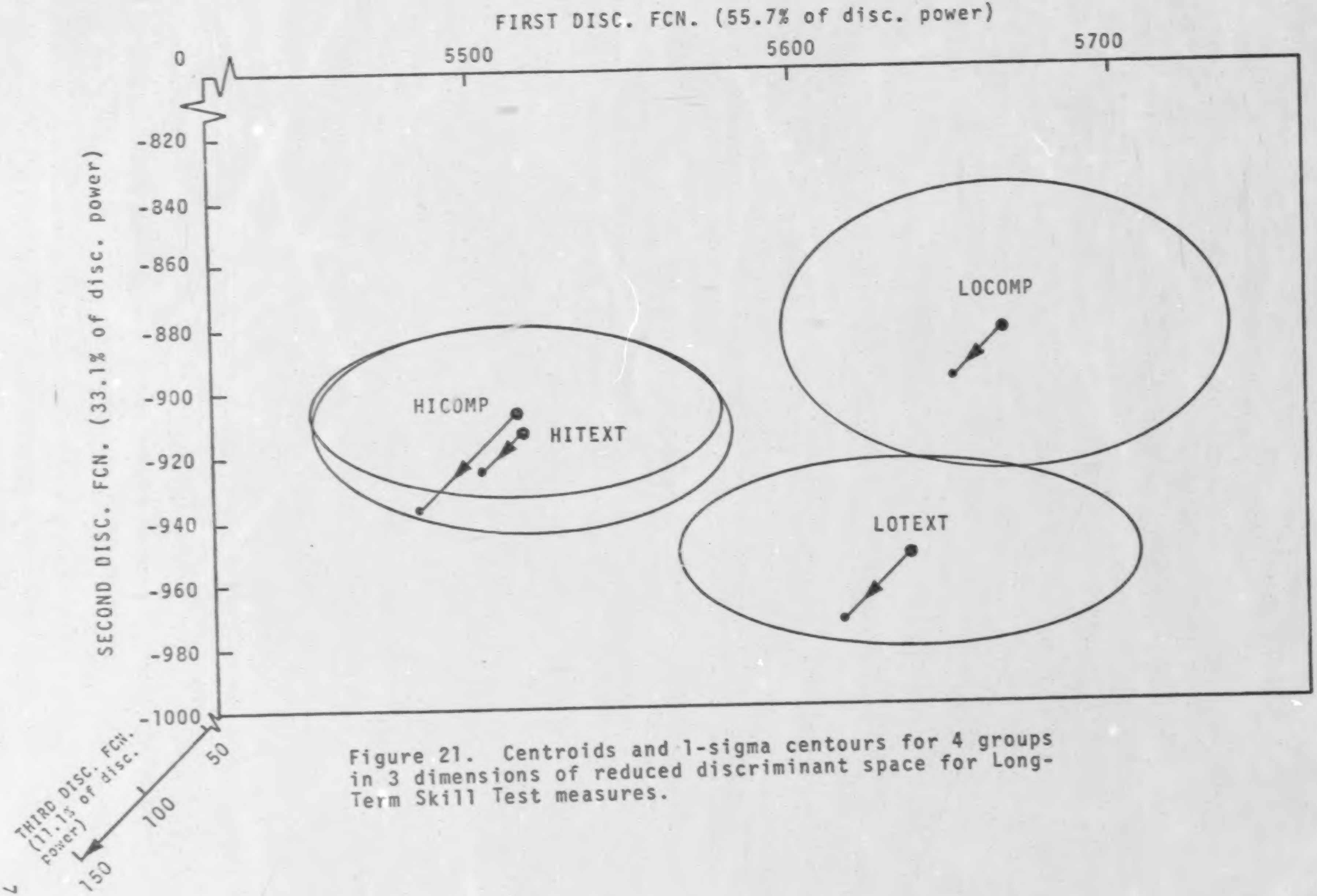


Figure 21. Centroids and 1-sigma centours for 4 groups in 3 dimensions of reduced discriminant space for Long-Term Skill Test measures.

5. *Summary of Results from the Discriminant Analyses*

The results from the series of discriminant analyses may be summarized as follows:

(a) *Aptitude Differences.* All of the analyses showed large differences in the performance of high and low aptitude students. The significant F-tests for generalized discrimination were probably due, in large part, to the discrimination between students at the different aptitude levels. There is no doubt that aptitude differences were generally more important than treatment differences.

The univariate analyses, discussed next, showed that this last statement does not hold for one variable, Time To Complete Training. In fact, this variable probably accounted for the good separation of training treatments in the first discriminant analysis. In the other discriminant analysis, which did not include Time To Complete Training, training treatments were not so well separated.

(b) *Training Treatment Differences.* The only good discrimination between training treatments at both aptitude levels occurred in the first discriminant analysis. As mentioned above, we felt this was primarily due to the Time To Complete Training variable. Differences between training treatments at the high aptitude level were slight for the Knowledge and Short-Term Skill measures and virtually nonexistent for the Long-Term Skill measures. Differences between training treatments at the low aptitude level were moderate for the Knowledge measures and considerable for both Short-Term and Long-Term Skill measures.

6. *Univariate Analysis*

While discriminant analysis was very useful for exploring the maximum possible discrimination between the groups that we had defined earlier, it provided no information about the relationships between the independent variables and *individual* dependent variables. To obtain this information we performed a series of 18 analyses of variance using all the dependent variables that are listed on pages 59 and 60, except the item scores for the skill tests. These analyses were performed on the same data base used for the discriminant analyses. The same four groups, or cells, were used to represent different levels of the independent variables. These were two-by-two analyses of variance with two levels of aptitude (high versus low ETST scores) and two kinds of treatment (CII versus PTI).

Table 3 presents a summary of the results from the 18 two-by-two analyses of variance. The F-values are presented for the treatment effect, the aptitude effect, and their interaction. Asterisks indicate the significance level. It must be kept in mind that these variables are not independent of one another, and that in a set of significance tests this large, some will reach significance purely by chance. We performed this set of analyses not in the sense of classical hypothesis testing but rather as a means of deriving an index of the apparent strength of the relationships between these 18 dependent variables and the independent variables of treatment and aptitude.

There is a special column in Table 3 labeled "Best" Treatment. This column is to inform the reader which treatment condition showed the best performance (e.g., shortest time to complete a skill test, highest score on a knowledge test, etc.). Entries were made in this column where the *treatment* effect approached/exceeded significance, or where the *interaction* approached/exceeded significance. In all cases where the *aptitude* effect was significant, the higher aptitude students performed "better" than the lower aptitude students, as would be expected from our earlier analyses. Inspection of Table 3 shows that the higher aptitude students often performed significantly better than the lower aptitude students, both in the short and long term.

TABLE 3

SUMMARY OF ANALYSES OF VARIANCE RESULTS RELATING 18 DEPENDENT VARIABLES TO TRAINING TREATMENT AND SCIENCE/MATH APTITUDE LEVELS

DEPENDENT VARIABLES		"BEST" TREATMENT	VALUES OF F		
No.	Description		Treatment	Aptitude	Interactio
1	Time to Complete Training Course	PTI	26.38**	2.00	0.00
2	No. Interactions with Proctor	PTI	2.23	1.12	0.59
3	Pre-Course Knowledge	CII	3.42	8.05**	0.55
4.	Short-Term Knowledge		0.43	72.43**	1.19
5	Short-Term Knowledge Gain (4-3)		0.00	54.26**	1.90
6	Long-Term Knowledge		0.27	44.20**	1.24
7	Long-Term Knowledge Gain (6-3)		0.05	28.36**	1.85
8	Forgetting (4-6)		0.13	2.51	0.26
	Short-Term Skill Test:				
9	Time to Complete All Items		0.31	21.45**	1.66
10	No. Timed-Out Items		0.56	10.90**	0.72
11	No. Errors on Regular Items		0.16	6.38*	1.47
12	No. Errors on Transfer Items		0.00	2.65	0.44
13	Total Errors		0.44	0.40	1.21
	Long-Term Skill Test:				
14	Time to Complete All Items	Low High PTI, CII	1.29	22.08**	5.63*
15	No. Timed-Out Items	Low High PTI, CII	0.66	14.58**	4.80*
16	No. Errors on Regular Items		0.00	16.00**	0.35
17	No. Errors on Transfer Items		0.90	5.64*	0.00
18	Total Errors		0.03	18.64**	0.30

* $p \leq .05$
** $p \leq .01$

Table 3 shows five analyses that suggest meaningful-treatment effects or aptitude-treatment interaction effects. Graphs of these effects were constructed to aid the interpretation of the results (Figures 22 through 26). The performance scales in these figures have been normalized across the 84 subjects and scaled to have a mean of 500 and a standard deviation of 10. Data had been scaled in this manner for the discriminant analysis programs.

The PTI students finished the training in significantly less time than did the CII students. Figure 22 shows approximately a 1 standard deviation difference between the training treatments at both aptitude levels. This difference was significant well beyond the .01 level.

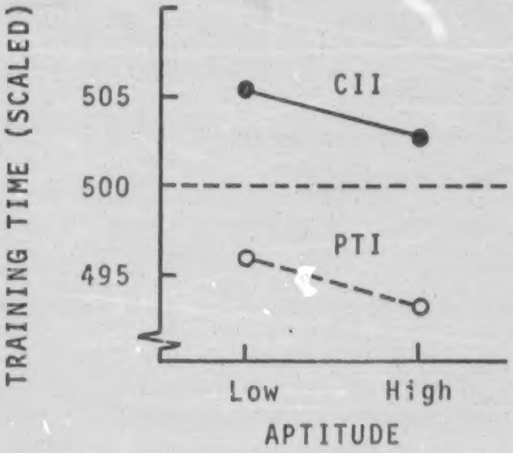


Figure 22. Time to Complete Training as a Function of Science/Math Aptitude and Training Treatment.

The PTI students initiated fewer interactions with the proctor. Figure 23 shows both low and high aptitude PTI students engaged in fewer than the average number of interactions with the proctor during the course. The low aptitude CII students had more than the average number of interactions, and the high aptitude CII students were at about the mean. Neither the main effects nor the interactions were statistically significant. However, these results are in accordance with the results of the analysis of the time to complete the course.

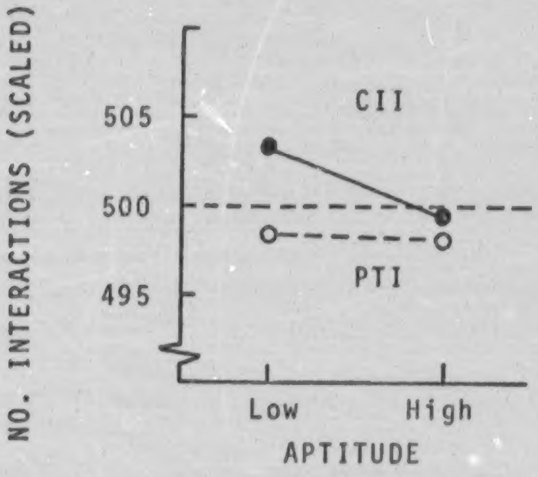


Figure 23. Number of Interactions as a Function of Science/Math Aptitude and Training Treatment.

The above results are even more interesting in light of the results on the Pre-Course Knowledge Test. We had randomly distributed students who were matched on GCT and ETST to the two training treatments. However, Figure 24 shows that the CII students generally scored better on the Pre-Course Knowledge Test than did the PTI students. Yet the PTI students finished the course in less time and with fewer interactions with the training proctor than did the CII students. The treatment effect on the Pre-Course Knowledge Test approached but did not meet statistical significance at the .05 level.

Two analyses revealed an aptitude/treatment interaction. Figures 25 and 26 show that low aptitude PTI students took less time to complete the Long-Term Skill Test and had fewer items terminated because of the time limit than did the low aptitude CII students. To a lesser extent, the reverse was true for high aptitude CII and PTI students. The low aptitude CII

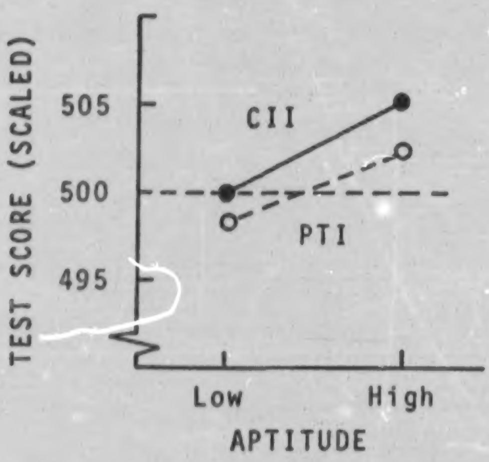


Figure 24. Pre-Course Knowledge as a Function of Science/Math Aptitude and Training Treatment.

students were about 1 standard deviation "worse" than average on both of these criteria. All three of the other groups were at the mean or "better." In both cases, the interactions were significant at the .05 level.

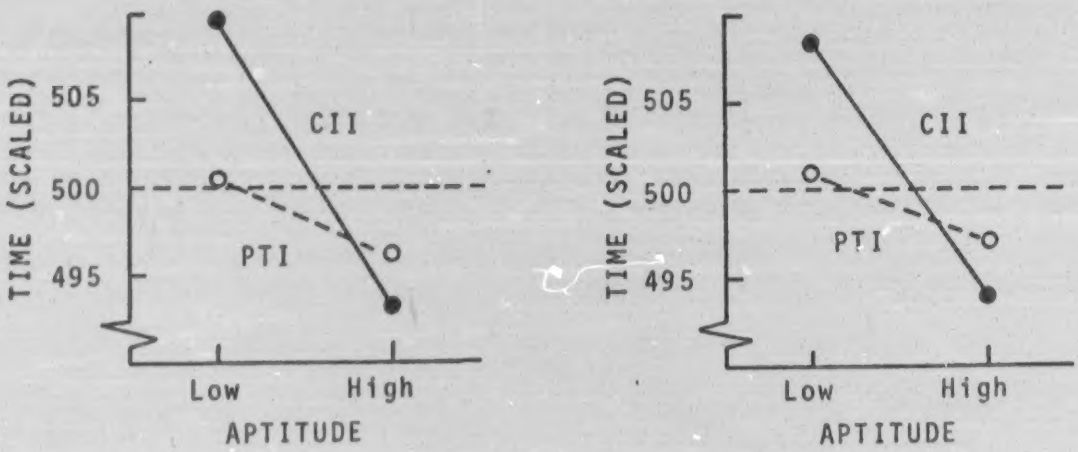


Figure 25. Time To Complete the Long-Term Skill Test as a Function of Science/Math Aptitude and Training Treatment.

Figure 26. Number of Timed-Out Items on the Long-Term Skill Test as a function of Science/Math Aptitude and Training Treatment.

The difference between the low aptitude CII and PTI groups on Time to Complete the Long-Term Skill Test was subjected to a t Test. The difference was significant at the .05 level. Because the number of timed-out items is logically correlated with the time to complete a test, we did not run a t Test on the low aptitude group difference shown in Figure 26. In reality, Figures 25 and 26 show two ways of investigating a single underlying phenomenon.

Before leaving the univariate analyses, we want to discuss two other results.

The univariate tests to this point have dealt with *science/math aptitude,* as measured by the ETST. Recall that Figure 15, in the preliminary analysis, showed a small but consistent superiority of the lower *verbal* aptitude PTI students over the lower *verbal* aptitude CII students in time to complete the Long-Term Skill Test. We prepared these data for analysis of variance by defining high and low verbal aptitude groups in the same manner as we had for science/math aptitude in the discriminant analyses and analyses of variance reported above.

Figure 27 shows a graph of the cell means for this analysis. The curves here resemble those in Figures 23, 25, and 26: The low aptitude CII group appears to be the "worst" performer. However, analysis of variance showed that neither the treatment nor interaction effects were statistically significant but the verbal aptitude effect was.

It will be recalled that three problems from the Short-Term Skill Test were embedded in the Long-Term Skill Test. Students did not have access to the textbooks nor opportunity to practice troubleshooting digital logic circuits during the long-term retention interval. Furthermore, students were instructed not to discuss the course with anyone; anecdotal evidence indicated that they followed those instructions to an extreme.

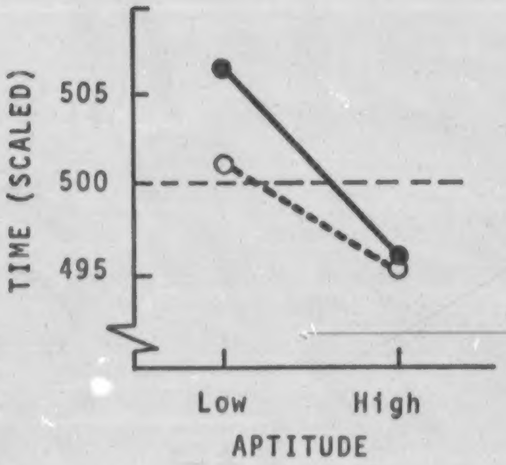


Figure 27. Time to Complete the Long-Term Skill Test as a Function of Verbal Aptitude and Training Treatment.

Group performance on the three identical items for the Short-Term and Long-Term Skill Tests was compared in order to evaluate possible differences in forgetting troubleshooting skill. In general, improvement, rather than forgetting, was evident. Students completed the three items in less time after the long-term retention interval than they did immediately after completing the course. There was no clear pattern of differences for different levels of the aptitude or training treatment variables.

VI. CONCLUSIONS AND RECOMMENDATIONS

We began this study by developing a relatively low-cost computerized instructional system to explore the feasibility of using such a system to alleviate the practical training problems in organizations plagued by limited funds and shortages of qualified instructors for highly varied curricula. We compared the computerized curriculum with a type of widely used non-computerized curriculum, the programmed text; we were very careful to make the comparison objective.

We discovered that high aptitude students were superior to the low aptitude students on all the post-course performance criteria, whether the criteria were measures of acquired knowledge or task performance. The training treatment had no differential effect on the performance of high aptitude students. Low aptitude students in the non-computer curriculum appeared to perform better on certain skill criteria than did low aptitude students in the computerized curriculum. Students in the non-computerized curriculum finished the training sooner than those in the computerized curriculum, regardless of aptitude level.

The results of the present study indicate that computerized instruction is not the optimum approach to at least some kinds of practical training problems. The computerized curriculum in the present study may be criticized as not representing the most elegant pedagogical use of a computer; however, this computerized curriculum *does* represent the main features of much of current computerized instruction. Insofar as much current CAI is, in reality, an automated teaching machine, or an automatic programmed text, the present CII curriculum is representative of that approach, even though we used a hard-copy text instead of the ubiquitous CRT to present textual information. Our approach was even a little more sophisticated than an automated teaching machine, because we used the computer to drive a laboratory simulation of the operational equipment of interest. Furthermore, we accomplished this with a minicomputer.

We spent considerable effort to develop a computer-controlled training environment that would virtually replace the teacher and the laboratory needed for training a relatively complex skill, troubleshooting digital logic circuits. In meeting the needs for appropriate control conditions, we rejected the typically used classroom-with-lecturer. We chose instead a curriculum that would benefit from the same thinking and organization as would the computerized curriculum, but would not require a computer. Our choice was programmed instruction.

This last step, the choice of an appropriate control, distinguishes the present study from many others that have compared "computerized" with "conventional" instruction. The results of the present study demonstrate why this step is crucially important. Our results reinforce the need for continued research and development of a sound theory and practice of instructional psychology.

It would be inappropriate, of course, to generalize the present results to *all* training problems. Many variables distinguish specific training problems, and our study addressed only a few. From our results and review of certain relevant literature, however, we suggest the following principles involving the training variables of the present study:

1. Barring the influence of relatively bizarre motivation, anxiety, and certain other variables, high aptitude students will usually do well under any reasonable training conditions. This generalization may be tempered by the observation of Bialek *et al.* (1973) that high aptitude military trainees, who are in classes that are aimed at the low aptitude trainees, may become "bored and restless," and may show a loss in achievement.

2. Lower aptitude students are very sensitive to training treatment. They may require realistic simulations of operational equipment (McFann, 1971); they may do poorly using CRT-presented material on mathematical concepts (Dick and Latta, 1969); and they may learn certain skills as well or better from a programmed text as from interaction with a computer-controlled laboratory (present study). Much additional research appears to be necessary before a set of general principles for training lower aptitude students can be formulated.

3. The computerized instructional approach may not always be the fastest means of training. While one CAI curriculum resulted in a large time savings compared to lecture/classroom training (Ford *et al.*, 1972), our computerized training was significantly *slower* than an equivalent programmed-text curriculum.

4. The computerized approach may require, at least at the initial stage of training, more proctor intervention and help than some other techniques.

5. If a computerized approach *is* called for in some training application, it may not be as expensive to implement as have the CAI systems of the past. Recent workers (Thomas, 1973; Brebner, 1973; Mecherikoff, 1974; the present study) have shown progress in implementing computerized instruction on relatively small, inexpensive systems. Also, there are continuing developments in expanding the number of terminals serviced by big systems so that the cost-per-hour of user time is reduced. The growing success of commercial time-sharing systems (e.g., General Electric's Mark III system) is evidence for hope along the latter lines.

While there may be hope for the future of individualized training, there is a great deal of work in this area yet to be done. Research in this area is time consuming and expensive. Hickey and Newton (1967) note four criteria for adequate research in training comparisons: The study should (1) involve at least five hours of instruction, (2) use more than 15 students in each group, (3) report the time to complete the training, and (4) report pre- and post-training results. The first criterion ensures that the study concerns training and curriculum problems as opposed to laboratory learning phenomena (e.g., paired-associate learning). The second criterion ensures the reliability of the results. The last two criteria ensure that at least the basic dependent variables are measured and related to students' pre-course abilities. The present study met all these criteria and at least one other most important one: equivalence of experimental and control curricula content.

Meeting those criteria, unfortunately, requires much larger research studies than those typically reported in the literature on human learning. As Locke (1971) stated, private industry is not keen on solving these problems with internal funds. Evidently, government agencies with a vested interest in this area are faced with the prospect of continuing to support training research, or accepting seat-of-the-pants training strategies that may be based on little more than (costly) fads. The results of the present study lead to the following recommendations:

1. Research in computerized instruction *must* include adequate control curricula for comparisons. Furthermore, such studies should devise means of realistically assessing the average amount of instructor time per student in the experimental and control conditions. Many research reports on computerized instruction do not cite what is often admitted in private, that a *higher* instructor-to-student ratio is present in the computerized curriculum, which was originally intended to replace the instructor, than in the "conventional" curriculum.

2. Research on optimizing instruction for individuals of varying aptitudes should focus on the lower aptitude students. It would be an overstatement to say that high aptitude students will take care of themselves in all cases; however, the results of the present study and those cited earlier suggest that

different training strategies do not usually result in large performance differences among high aptitude students. On the other hand, there is adequate evidence of significant performance differences among low aptitude students who are subjected to different training treatments. Research in this area should continue. It should be noted that "low aptitude" is a relative term. In the present study, we dealt with students whose math/science aptitude was low relative to the sophistication of the digital logic training material. Probably, their math/science aptitude, and certainly their general verbal aptitude, would be considered moderate relative to training in infantry skills in the studies by Bialek discussed earlier.

3. The instructional practitioner who cannot wait for the results of further research relevant to his training area should carefully consider relatively inexpensive alternatives, like high-quality programmed instruction, before trading in his classrooms and lecturers for computerized instruction. The course reconstruction and reformatting that his staff must perform *before beginning* to implement a computerized curriculum would constitute the *bulk* of the work and expense necessary for a high-quality programmed instruction curriculum.

REFERENCES

Anderson, T. W. *An introduction to multivariate statistical analysis.* New York: John Wiley & Sons, 1958.

Bialek, H. M., Taylor, J. E., & Hauke, R. N. Instructional strategies for training men of high and low aptitude. *HumRRO Technical Report 73-10,* 1973.

Bracht, G. H. The relationship of treatment tasks, personological variables, and dependent variables to aptitude-treatment interactions. *University of Colorado, Doctoral Dissertation,* 1969.

Brebner, A., & Hallworth, H. J. Computer-assisted instruction on a small computer. *International Journal of Man-Machine Studies,* 1973, *5,* 437-442.

Cooley, W. W., & Glaser, R. The computer and individualized instruction. *Science,* 1969, *166,* 574-582.

Cooley, W. W., & Lohnes, P. R. *Multivariate procedures for the behavioral sciences.* New York: John Wiley & Sons, 1962.

Cronbach, L. J. The two disciplines of scientific psychology. *American Psychologist,* 1957, *12,* 671-684.

Cronbach, L. J. How can instruction be adapted to individual differences. In Gagné, R. M. (Ed.), *Learning and Individual Differences.* Columbus, Ohio: Charles E. Merrill Books, Inc., 1967.

Davis, R. H., Denny, M. R., & Marzocco, F. N. Interaction of individual differences with mode of presenting programmed instruction. *Journal of Educational Psychology,* 1970, *61,* 198-204.

Dick, W., & Latta, R. F. Comparative effects of ability and presentation mode in computer-assisted instruction and programmed instruction. *Florida State University, CAI Center, Tech. Memo No. 5,* 1969.

Dwyer, T. A. Some principles for the human use of computers in education. *International Journal of Man-Machine Studies,* 1971, *3,* 219-239.

Estelita, T. A. Educational projects for a digital logic laboratory. *University of Illinois, Department of Computer Science, Report No. UIUCDCS-R-72-535,* 1972.

Farr, M. J. Computer-assisted instruction. *Naval Research Reviews*, 1972, *25*, 8-16.

Ford, J. D., Jr., & Slough, D. A. Development and evaluation of computer assisted instruction for Navy electronics training: Alternating current fundamentals. *Naval Personnel and Training Research Laboratory, Research Report SRR 70-32*, 1970.

Ford, J. D., Jr., Slough, D. A., & Hurlock, R. E. Computer assisted instruction in Navy technical training using a small dedicated computer system: Final report. *Naval Personnel and Training Research Laboratory, Research Report SRR 73-13*, 1972.

Glaser, R., & Resnick, L. B. Instructional Psychology. *Annual Review of Psychology*, 1972, *23*, 207-276.

Hammond, A. L. Computer-assisted instruction: Two major demonstrations. *Science*, 1972, *176*, 1110-1112.

Hansen, D. N. Current research development in computer-assisted instruction. *Florida State University, CAI Center, Tech. Memo No. 17*, 1970.

Hickey, A. E., & Newton, J. M. Computer-assisted instruction: A survey of the literature. (2nd ed.) *ENTELEK INC.*, 1967.

Hickey, A. E. Computer-assisted instruction information exchange: Final report. *ENTELEK INC., Tech. Rep.*, 1970.

Hurlock, R. E. Development and evaluation of computer assisted instruction for Navy electronics training: Inductance. *Naval Personnel and Training Research Laboratory, Research Report SRR 71-22*, 1972.

Locke, R. W. Has the education industry lost its nerve? *Saturday Review*, January 16, 1971, *54*, 42-44+.

McFann, H. H. Training strategies and individual differences. *HumRRO, Professional Paper No. 12-71*, 1971.

Mecherikoff, M. Concept learning in the aural analysis of passing sonar signals. *Human Factors Research, Inc., Tech. Rep. 776-5*, 1974.

Rao, C. R. *Advanced statistical methods in biometric research.* New York: John Wiley & Sons, 1952.

Rigney, J. W., Towne, D. M., King, C. A., & Langston, E. T. Computer-aided performance training for diagnostic and procedural tasks. *USC Behavioral Technological Laboratories, Tech. Rep. No. 70*, 1972.

Rulon, P. J. The stanine and the separile: A fable. *Personnel Psychology*, 1951, *4*, 99-114.

Rulon, P. J. Distinctions between discriminant and regression analyses and a geometric interpretation of the discriminant function. *Harvard Educational Review*, 1951, *21*, 80-90.

Salisbury, A. B. An overview of CAI. *Educational Technology*, 1971, *11*, 48-50.

Simpson, H. K., Wylie, C. D., & DePauli, J. F. A study of maintenance training requirements common to the three models of the AN/SQS-26 sonar. *Human Factors Research, Inc., Tech. Rep. 1704-1*, Part II, Instructor and Trainee Guides, 1971.

Stem, H. W. Development and evaluation of performance-oriented test equipment training procedures. *Naval Personnel and Training Research Laboratory, Research Report SRR 72-11*, 1972.

Stolurow, L. N. Computer assisted instruction. *American Data Processing, Inc., Education Automation Monograph Series*, 1968.

Suppes, P., Jerman, M., & Brian, D. *Computer assisted instruction.* New York: Academic Press, 1968, 385.

Thomas, P. A. V. The role of the mini-computer in computer-aided instruction. *International Journal of Man-Machine Studies*, 1973, *5*, 371-383.

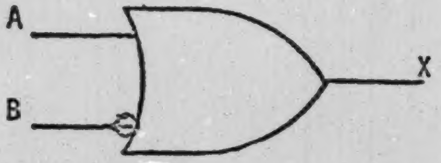
Tiedeman, D. V. The utility of the discriminant function in psychological and guidance investigations. *Harvard Educational Review*, 1951, *21*, 71-80.

APPENDIX A

Excerpt from Chapter 5, "R-S Flip-Flop," in the PTI textbook

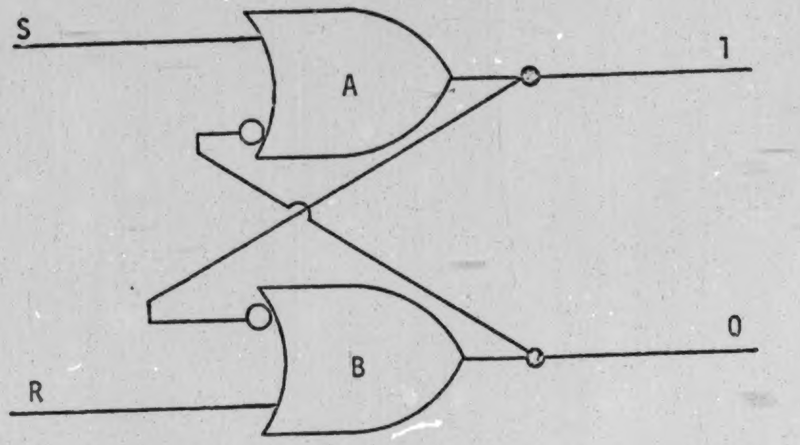
A Programmed Text in DIGITAL TECHNOLOGY

One of the most important characteristics of the R-S flip-flop is that it has memory. It retains a state after the input pulses are removed. Somewhat surprisingly, the R-S flip-flop, with memory, can be constructed of logic gates that lack memory. There are a number of ways that this can be accomplished. The method we will consider here is to combine two OR gates, each of which has one negated input. This gate and its truth table are shown below.



A	B	X
0	0	1
0	1	0
1	0	1
1	1	1

Let us consider the manner in which the two OR gates, each with one negated input, can accomplish what is referred to as "latching." An R-S flip-flop is shown below. We will first explain how to latch it in the 1 state.



Suppose the input at S is 1 and the input at R is 0. Gate *A* will output a 1 and that output will be presented to the upper terminal of Gate *B*. But this is the inverted input terminal for Gate *B* so that, along with the 0 input at the lower terminal, Gate *B* will output a 0. This 0 is presented to the lower input terminal of Gate *A*. Since this is the inverted input terminal for *A*, it will cause *A* to output a 1 even if the 1 input at the upper *A* terminal were not there.

A-5 /A-6

ITEM 90

Question

While in the 1 state, after the input pulse is removed, the upper and lower inputs to Gate A on page 7-21 are:

1. 0 and 0.
2. 0 and 1.
3. 1 and 0.
4. 1 and 1.

1. CORRECT. Continue.
2. INCORRECT. Reread the previous frame and answer again.
3. INCORRECT. Reread the previous frame and answer again.
4. INCORRECT. Reread the previous frame and answer again.

The flip-flop can be latched in the 0 state by reversing the process described above. Suppose the input at S is 0 and the input at R is 1. Gate *B* will output a 1 and that output will be presented to the lower terminal of Gate *A*. But this is the inverted-input terminal for Gate *A* so that, along with the 0 input at the upper terminal, Gate *A* will output a 0. This 0 is presented to the upper input terminal of Gate *B*. Since this is the inverted input terminal for *B*, it will cause *B* to output a 1 even if the 1 input at the lower *B* terminal were not there.

The output of Gate *B* does not change when R is now set to 0 because the 0 at the upper, inverted-input terminal causes Gate *B* to still output a 1. Gate *B* continually forces Gate *A* to output a 0 and Gate *A* continually forces Gate *B* to output a 1, even though S and R are resting at 0.

Think about this a while before going on.

ITEM 91

Question

While the flip-flop is latched in the 0 state, with 0s at the S and R inputs, the inputs at the upper and lower terminals of Gate *A* on page 7-21 will be:

1. 0 and 0.
2. 0 and 1.
3. 1 and 0.
4. 1 and 1.

1. INCORRECT. Reread the previous frame and answer again.
2. CORRECT. Continue.
3. INCORRECT. Reread the previous frame and answer again.
4. INCORRECT. Reread the previous frame and answer again.

ITEM 92

Demonstration

Refer to Figure 2.

Note the levels present at the various points in the logic diagram for all possible input conditions.

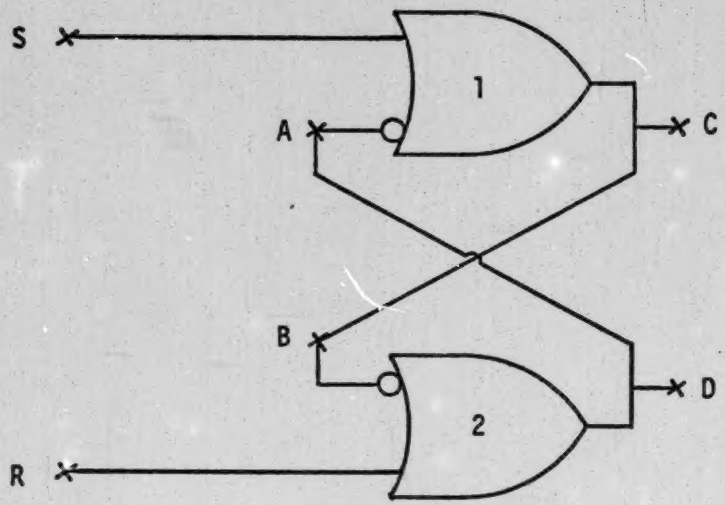


FIGURE 2

S	R	A	B	C	D
0	0	Retains prior ordinary state			
0	1	1	0	0	1
1	0	0	1	1	0
1	1	1	1	1	1

ITEM 93

Question

When the flip-flop is in the 1 state, the levels at the lower input of gate 1 and at the upper input of gate 2 are:

1. 0 and 0.
2. 0 and 1.
3. 1 and 0.
4. 1 and 1.

1. INCORRECT. Repeat the last demonstration and answer again.
2. CORRECT. Continue.
3. INCORRECT. Repeat the last demonstration and answer again.
4. INCORRECT. Repeat the last demonstration and answer again.

The foregoing discussion is rather complicated, but essential to an understanding of the subject of flip-flops. Read it over until you feel confident that you fully understand it. Repeat the demonstrations and questions if you like.

The following is a complete truth table for the R-S flip-flop.

	input		output	
	S	R	1	0
(1)	0	0	Retains initial ordinary state	
(2)	0	1	0	1
(3)	1	0	1	0
(4)	1	1	1	1

Consider row 1 of the table. When two low (0) inputs are received by the flip-flop, the output condition which results is dependent upon the initial condition of the gate. Why this is true should be quite obvious: the 0s at the input terminals do not influence the condition of the flip-flop at all. The flip-flop remains in whatever ordinary state it was in before the inputs were made.

Regardless of the initial state of the flip-flop, we see that from row 3 of the table a 1 input at the S terminal and a 0 input at the R terminal cause the flip-flop to go to the 1 state.

Now examine the bottom row of the table. We see that if both inputs receive a high (1) level, both outputs of the flip-flop will go to 1. When the high levels are removed, the flip-flop could latch in either the 1 state or the 0 state, depending upon which input is removed first.

ITEM 94

Question

The flip-flop will retain a prior ordinary state when:

1. 1s are presented at both inputs.
2. 0s are presented at both inputs.
3. Either a 1 and a 0 or a 0 and 1 are presented at the inputs.
4. Both (1) and (2) are correct.

1. INCORRECT. Reread the previous frame and answer again.
2. CORRECT. Continue.
3. INCORRECT. Reread the previous frame and answer again.
4. INCORRECT. Reread the previous frame and answer again.

ITEM 95

Troubleshooting Exercise

Refer to Figure 3. At least one of these three R-S flip-flops is malfunctioning. Determine which one(s).

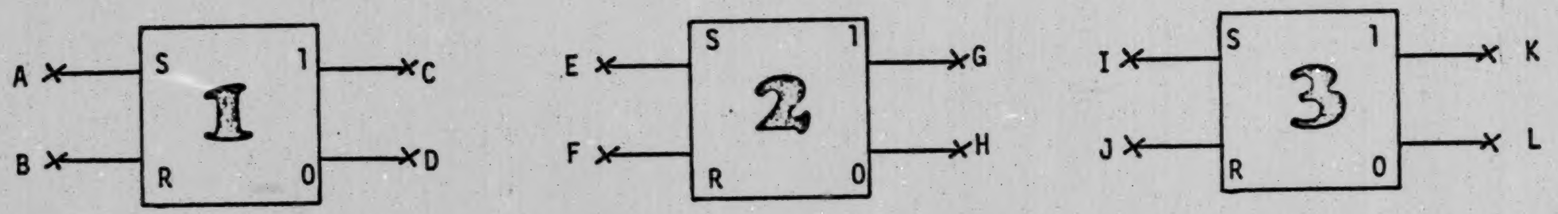

A
B
S
R
1
0
1
C
D
E
F
S
R
1
0
2
G
H
I
J
S
R
1
0
3
K
L

FIGURE 3

A	B	C	D	E	F	G	H	I	J	K	L
0	0	Retains prior ordinary state		0	0	Retains prior ordinary state		0	0	Retains prior ordinary state	
0	1	0	1	0	1	0	1	0	1	1	0
1	0	1	0	1	0	1	0	1	0	0	1
1	1	1	1	1	1	1	1	1	1	1	1

ITEM 96

Question

The defective flip-flop(s) have number(s) _____.

A-45/A-46/
A-48

The correct response is 3. If you made this response, continue.

If you made another response, you are incorrect.

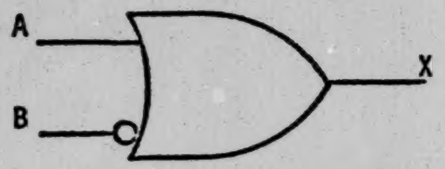
If you did not make the correct response, do the exercise again. If you continue to have difficulty, ask the instructor for help.

APPENDIX B

Excerpt from Chapter 5, "R-S Flip-Flop," in the CII textbook

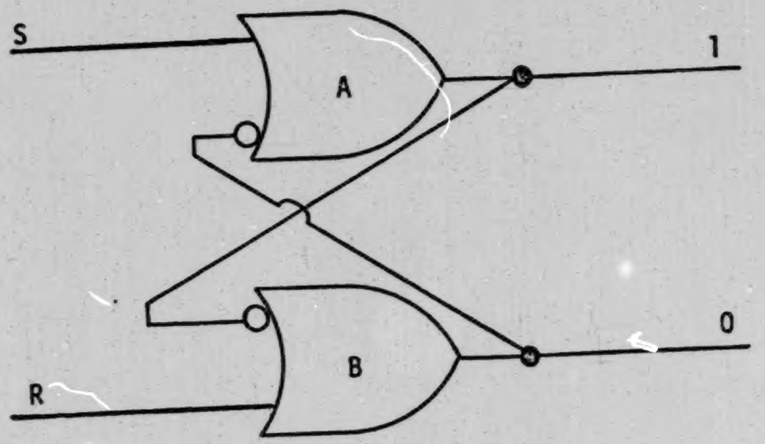
A Programmed Text in DIGITAL TECHNOLOGY

One of the most important characteristics of the R-S flip-flop is that it has memory. It retains a state after the input pulses are removed. Somewhat surprisingly, the R-S flip-flop, with memory, can be constructed of logic gates that lack memory. There are a number of ways this can be accomplished. The method we will consider here is to combine two OR gates, each of which has one negated input. This gate and its truth table are shown below.



A	B	X
0	0	1
0	1	0
1	0	1
1	1	1

Let us consider the manner in which the two OR gates, each with one negated input, accomplish what is referred to as "latching." An R-S flip-flop is shown below. We will first explain how to latch it in the 1 state.



Suppose the input at S is 1 and the input at R is 0. Gate *A* will output a 1 and that output will be presented to the upper terminal of Gate *B*. But this is the inverted input terminal for Gate *B* so that, along with the 0 input at the lower terminal, Gate *B* will output a 0. This 0 is presented to the lower input terminal of Gate *A*. Since this is the inverted input terminal of *A*, it will cause *A* to output a 1 even if the 1 input at the upper *A* terminal were not there.

B-5/B-6

ITEM 90

Question

number
ENTER

While in the 1 state, after the input pulse is removed, the upper and lower inputs to gate *A* on page 7-16 are:

1. 0 and 0.
2. 0 and 1.
3. 1 and 0.
4. 1 and 1.

ADVANCE

The flip-flop can be latched in the 0 state by reversing the process described above. Suppose the input at S is 0 and the input at R is 1. Gate *B* will output a 1 and that output will be presented to the lower terminal of Gate *A*. But this is the inverted input terminal for Gate *A* so that, along with the 0 input at the upper terminal, Gate *A* will output a 0. This 0 is presented to the upper input terminal of Gate *B*. Since this is the inverted input terminal for *B*, it will cause *B* to output a 1 even if the 1 input at the lower *B* terminal were not there.

The output of Gate *B* does not change when R is now set to 0 because the 0 at the upper, inverted input terminal causes Gate *B* to still output a 1. Gate *B* continually forces Gate *A* to output a 0 and Gate *A* continually forces Gate *B* to output a 1, even though S and R are resting at 0.

Think about this awhile before going on.

ITEM 91

Question

number
ENTER

While the flip-flop is latched in the 0 state, with 0s at the S and R inputs, the inputs at the upper and lower terminals of gate *A* on page 7-16 will be:

1: 0 and 0.
2. 0 and 1.
3. 1 and 0.
4. 1 and 1.

ADVANCE

ITEM 92

Demonstration - Overlay 16

Refer to Figure 2.

R=1
ENTER

This flip-flop is resting in the 1 state. Observe the levels present at the various points in the logic diagram.

R=0
ENTER

Now place the flip-flop in the 0 state by entering R = 1. Observe the levels at various points in the diagram.

S=1
ENTER

Enter R = 0 and observe that the flip-flop maintains, or is resting in, the 0 state.

S=0
ENTER

Put the flip-flop back in the 1 state, then, by removing the input from S, note that the flip-flop is resting in the 1 state.

Continue manipulating the inputs at S and R until you feel you are thoroughly familiar with the operation of this circuit.

ADVANCE

NOTE: This demonstration frame corresponds with the overlay shown in Figure 4 in the main text.

ITEM 93

Question

number
ENTER

When the flip-flop is in the 1 state, the levels at the lower input of gate 1 and at the upper input of gate 2 are:

1. 0 and 0.
2. 0 and 1.
3. 1 and 0.
4. 1 and 1.

ADVANCE

The foregoing discussion is rather complicated, but essential to an understanding of the subject of flip-flops. Read it over until you feel confident that you fully understand it. Repeat the demonstrations and questions if you like.

The following is a complete truth table for the R-S flip-flop.

	input		output	
	S	R	1	0
(1)	0	0	Retains initial ordinary state	
(2)	0	1	0	1
(3)	1	0	1	0
(4)	1	1	1	1

Consider row 1 of the table. When two low (0) inputs are received by the flip-flop, the output condition which results is dependent upon the initial condition of the gate. Why this is true should be quite obvious: the 0s at the input terminals do not influence the condition of the flip-flop at all. The flip-flop remains in whatever ordinary state it was in before the inputs were made.

Regardless of the initial state of the flip-flop, we see that from row 3 of the table a 1 input at the S terminal and a 0 input at the R terminal cause the flip-flop to go to the 1 state.

Now examine the bottom row of the table. We see that if both inputs receive a high (1) level, both outputs of the flip-flop will go to 1. When the high levels are removed, the flip-flop could latch in either the 1 state or the 0 state, depending upon which input is removed first.

ITEM 94

Question

number
ENTER

The flip-flop will retain a prior ordinary state when:

1. 1s are presented at both inputs.
2. 0s are presented at both inputs.
3. Either a 1 and a 0 or a 0 and 1 are presented at the inputs.
4. Both (1) and (2) are correct.

ADVANCE

ITEM 95

Troubleshooting Exercise - Overlay 17

Refer to Figure 3. At least one of these three R-S flip-flops is malfunctioning. Determine which one(s).

ITEM 96

Question

number, ...
ENTER

The defective flip-flop(s) have number(s)_____.

ADVANCE

APPENDIX C

Knowledge Test

Name ____________________

Number ____________________

DIGITAL TECHNOLOGY

FINAL

Do not open this test booklet until your instructor tells you to.

This test consists of 40 multiple-choice questions. In the questions that follow, choose the single response that is most correct. Read each question completely and carefully before answering.

NOTE: Sometimes you may read the answer and immediately decide that one answer is correct. Do not stop there. It may be that more than one answer is correct, and the last alternative answer may indicate multiple-correct answers.

1. In a three-branch parallel switching circuit, a signal will pass from one side of the circuit to the other:
    - a. When all three switches are closed.
    - b. When any single switch is closed.
    - c. When all three switches are open.
    - d. Both (a) and (b) are correct.

2. In a negative logic system:
    - a. A 1 will be represented by a +1 volt, and a zero will be represented by 0 volts.
    - b. If a 1 were represented by -5 volts, a 0 might be represented by -10 volts.
    - c. If a 1 were represented by 0 volts, a 0 might be represented by -1 volt.
    - d. If a 1 were represented by -2 volts, a 0 might be represented by +2 volts.

3. Which of the following statements about the AND gate is incorrect?
    - a. It always has one output.
    - b. It always has two or more inputs.
    - c. It always introduces a time delay.
    - d. An active level always occurs at the output when there are active levels on all inputs simultaneously.

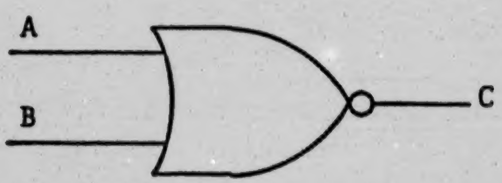
4. Refer to the table. The top and bottom values in this table should be:

a. 0 0.
b. 0 1.
c. 1 0.
d. 1 1.

A	B	C	A x B x C
0	0	0	?
0	0	1	0
0	1	0	0
0	1	1	0
1	0	0	0
1	0	1	0
1	1	0	0
1	1	1	?

5. Refer to the figure. The Boolean expression describing the logic function shown is:

a. $A + B = \overline{C}$.
b. $\overline{A} + \overline{B} = C$.
c. $\overline{A + B} = \overline{C}$.
d. $\overline{A} + \overline{B} = \overline{C}$.



6. The Boolean expression for the NOR gate is:

a. $A + B = C$.
b. $A + B = \overline{C}$.
c. $A \times B = C$
d. $A \times B + \overline{C}$

7. Refer to the table. The Boolean expression that should appear at the top of the right-hand column is:

a. $\overline{A} + B$.
b. $A + \overline{B}$.
c. $\overline{A \times B}$.
d. $\overline{A} \times \overline{B}$.

Input		Output
A	B	?
0	0	1
0	1	0
1	0	0
1	1	0

8. An OR gate can be constructed of

   a. an AND gate with inverted input.

   b. an AND gate with inverted inputs and output.

   c. an OR gate with inverted inputs and output.

   d. a NOR gate with inverted output.

9. The difference between the logic functions that have the Boolean expressions $\bar{A} + \bar{B} = C$ and $A + B = \bar{C}$ is that:

   a. The first has inverters on the inputs, the second on the output.

   b. The first has inverters on the output, the second on the inputs.

   c. They both have inverters in the same locations, but the expressions have been stated differently.

   d. One is constructed of an OR gate, the other of an AND gate.

10. Refer to the table. The Boolean expression that should appear at the top of the right-hand column is:

    a. $\bar{A} \times \bar{B}$.

    b. $\overline{A + B}$.

    c. $\overline{\bar{A} + \bar{B}}$.

    d. $\overline{A \times B}$.

A	B	?
0	0	1
0	1	1
1	0	1
1	1	0

11. A logic function which satisfies the Boolean expression A x (B + C) consists of

    a. a two-input OR gate connected to one input of a two-input AND gate.

    b. a two-input AND gate connected to one input of a two-input OR gate.

    c. two AND gates with their outputs connected to an OR gate.

    d. a three-input OR gate connected to one input of a two-input AND gate.

12. If a simple switching circuit is represented by the Boolean expression (A + B) x C,

    a. A and B and C must all be closed to close the circuit.

    b. closing A and B will close the circuit.

    c. closing A and C will close the circuit.

    d. Both "a" and "b" are correct.

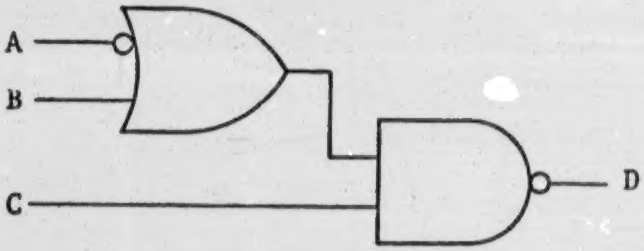
13. Refer to the figure. The Boolean expression describing the logic function shown is:

    a. $(\overline{A} + B)\ x\ C = \overline{D}$.

    b. $A + (\overline{B\ x\ C}) = \overline{D}$.

    c. $\overline{(A + B)\ x\ C} = \overline{D}$.

    d. $\overline{(A + \overline{B})\ x\ \overline{C}} = D$.



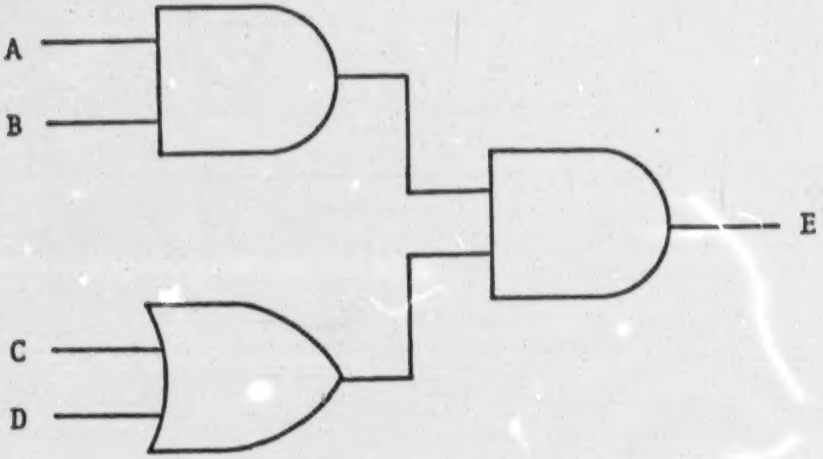
14. Refer to the figure. The Boolean expression describing the logic function shown is:

a. (A x C) + (B x D) = E.

b. (A x B) + (C x D) = E.

c. (A x B) x (C + D) = E.

d. (A x B) + (A x C) + (A x D) + (B x C) + (B x D) =



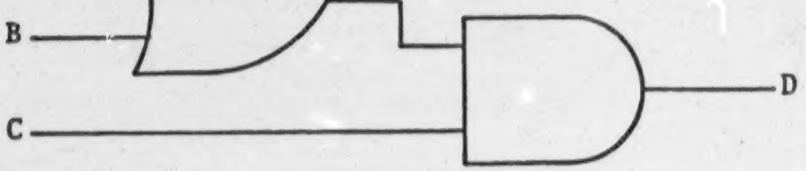
15. Refer to the figure. The Boolean expression describing the logic function shown is:

a. (A x B) + (B x C) = D.

b. (A + B) + C = D.

c. (A x B) + C = D.

d. (A + B) x C = D.



16. Logic devices with memory

    a. are similar to logic devices without memory because their output condition depends solely upon their input condition.
    b. can be constructed of logic devices without memory.
    c. work like an automobile horn.
    d. are too large to be used in computers.

17. An unclocked R-S flip-flop, when presented with two 0s,

    a. reverses state.
    b. goes to the 0 state.
    c. goes to the 1 state.
    d. retains its initial state.

18. The R-S, J-K, and D flip-flops have in common that:

    a. they retain a state even after their inputs have been removed.
    b. their output condition depends upon input conditions at a particular point in time.
    c. their output condition depends upon input conditions in the past.
    d. All of the above are correct.

19. Clocks are most useful for

    a. changing the states of flip-flops.
    b. controlling the precise time at which a change of state of a flip-flop occurs.
    c. establishing the initial state of a flip-flop so that it is "enabled" for triggering.
    d. keeping the flip-flop from "running away."

20. One of the problems with both clocked and non-clocked R-S flip-flops is that:

    a. they both have an indeterminate state.
    b. the precise time at which they change state cannot be controlled with accuracy.
    c. they retain their initial state if presented with two "1" pulses.
    d. they reverse their initial state if presented with two "0" pulses.

21. The D flip-flop

    a. has four states.
    b. has only two states.
    c. has two determinate states and two indeterminate states.
    d. has four determinate states.

22. If a D flip-flop receives a "0" pulse, the levels at the "1" and "0" output terminals after clocking will be, in order:

a. 0 0.

b. 0 1.

c. 1 0.

d. 1 1.

23. The J-K flip-flop

a. has the same truth table as the (unclocked) R-S flip-flop.

b. has the same truth table as the D flip-flop.

c. has the same truth table as the clocked R-S flip-flop.

d. has the same truth table as the D flip-flop, except for the indeterminate and complementing states.

24. If a J-K flip-flop is in the "0" state, and a 1 is placed on the J terminal and a 0 on the K terminal,

a. it will go to the "1" state at the start of the clock pulse.

b. it will go to the "0" state at the start of the clock pulse.

c. it will go to the "1" state at the end of the clock pulse.

d. it will go to the "0" state at the end of the clock pulse.

25. When two 0s are presented on the input terminals of a J-K flip-flop, and the device is clocked,

   a. it retains its initial state.
   b. it goes to the 0 state.
   c. it goes to the 1 state.
   d. it complements its initial state.

26. A four-bit shift register

   a. consists of four flip-flops.
   b. consists of a circuit with four storage positions, though these do not necessarily correspond to the number of flip-flops.
   c. can only be constructed of J-K flip-flops.
   d. may consist of one four-bit flip-flop.

27. If a four-bit shift register, consisting of four stages, A, B, C, and D, initially contains the binary number 1101, and then the input is put in the 0 state, after three clock pulses C and D will contain:

   a. 00
   b. 01
   c. 10
   d. 11

28. If a sixty-seven-bit shift register contains 67 1s, it will take

    a. 133 clock pulses to clear the register and fill it with 0s.
    b. 134 clock pulses to clear the register and fill it with 0s.
    c. 68 clock pulses to clear the register.
    d. 67 clock pulses to clear the register.

29. Zeroes and ones shift between stages of a J-K flip-flop shift register

    a. as soon as the clock pulse occurs.
    b. as soon as the clock pulse terminates.
    c. as soon as the input pulse is received.
    d. as soon as the input pulse and clock pulse occur.

30. A ring counter

    a. is a divider with the output connected back to the input.
    b. is a divider with the output inverted and connected back to the input.
    c. is a shift register with the output inverted and connected back to the input.
    d. is a shift register with the output connected back to the input.

31. If a four-stage ring counter, with stages A, B, C, and D, initially holds the binary number 1101, its state after three clock pulses will be

a. 1110

b. 0111

c. 1011

d. 1101

32. If a four-stage switch-tail ring counter, with stages A, B, C, and D, initially holds the binary number 1101, its state after three clock pulses will be:

a. 0110

b. 1011

c. 0010

d. 0101

33. If a four-stage switch-tail ring counter initially contains the binary number 1111,

a. in four clock pulses it will contain the binary number 1111.

b. in four clock pulses it will contain the binary number 0000.

c. in eight clock pulses it will contain the binary number 0001.

d. in eight clock pulses it will contain the binary number 1110.

34. A divide-by-sixteen divider, consisting of R-S flip-flops,

a. would have two stages.

b. would have three stages.

c. would have four stages.

d. could not be constructed. because dividers must contain J-K flip-flops.

35. In a divide-by-sixteen divider, the output of the first flip-flop

a. changes at the same rate as the input of the first flip-flop.

b. changes at one-fourth the rate of the input of the first flip-flop.

c. changes at half the rate of the input of the first flip-flop.

d. changes at twice the rate of the input of the first flip-flop.

36. The J-K terminals of a divide-by-sixteen divider

a. are eliminated.

b. are tied together and connected to the clock.

c. are tied together and continuously enabled by a 1 level.

d. are tied together and grounded.

37. A divide-by-32 divider would contain

a. 4 stages.

b. 5 stages.

c. 6 stages.

d. 7 stages.

38. A multiplexer

   a. switches information from several inputs to a single output.
   b. switches information from a single input to several outputs.
   c. stores information from several inputs before switching it to an output.
   d. delays information between input and output.

39. A ring counter is used in a multiplexer to:

   a. switch each input channel, in turn, to the output channel.
   b. switch each output channel, in turn, to the input channel.
   c. recirculate the input pulses for one cycle before switching them to the output.
   d. circulate the input through each AND gate before switching it to the output.

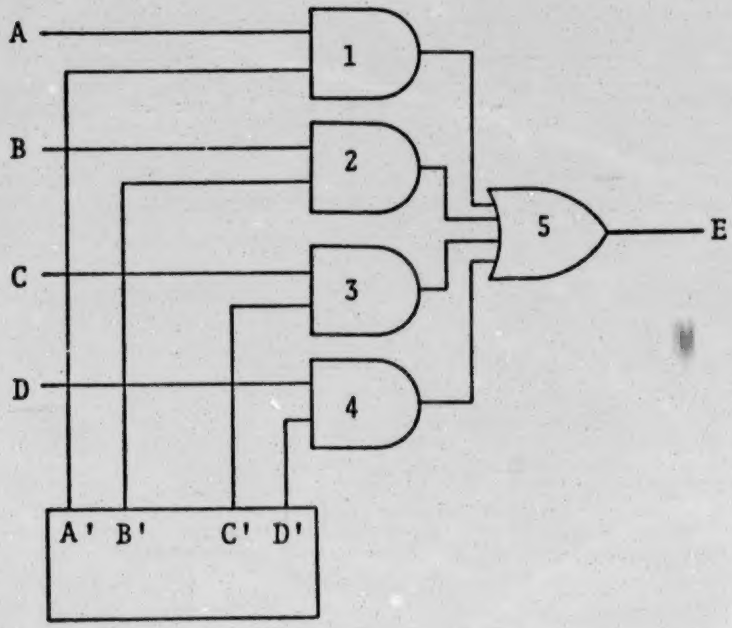
40. Refer to the figure. The levels on points A, B, C, and D are 1, 0, 1, 0, and a 1 is circulating in the ring counter, beginning initially at A'. The output at point E will read, across time,

a. 0000.

b. 0101.

c. 1010.

d. 1111.



APPENDIX D

Annotated Instructions To Students for the Skill Tests

FORM A: SHORT-TERM SKILL TEST

SUPER LOGIC PROBLEMS

A. You have up to 5 minutes to explore Logic Block #1. Use the Grey Box to put *1*'s and *0*'s to the upper and lower inputs of this logic block. Use the probe to explore what happens to the outputs of the different components within Logic Block #1. Ⓣ

[If necessary, help the student wire up this example.]

Okay, time is up--we will go on to a troubleshooting problem.

[Disconnect LB #1 and connect LB #2.]

B. There is one fault or error in Logic Block #2. Find it as quickly as you can and describe it to me. Ⓣ

[Gate 1 is bad; it behaves as an OR gate instead of an AND gate.]

[Disconnect LB #2 and connect LB #3.]

C. There is one fault in Logic Block #3. Find it as quickly as you can and describe it to me. Ⓣ

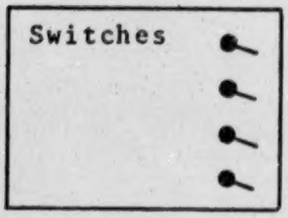
[Faulty output of Gate 3--OUTPUT REMAINS HIGH or may be interpreted as an input from Gate 4 pulling output of Gate 3 HIGH.]

[Disconnect LB #3 and connect LB #4.]

D. There is one fault in Logic Block #4. Find it as quickly as you can and describe it to me. Ⓣ

[Faulty input of Gate 4--INPUT REMAINS LOW and OUTPUT REMAINS HIGH.]

FORM A: SHORT-TERM SKILL TEST



HALF ADDER PROBLEMS

A. You have learned about shift registers and how to enter information into them. There are three numbers on this [give to student] Scratch Sheet. In a moment, I want you to enter the first number into the first shift register. I will connect the wires to the first shift register [connect]. We press the clock button in order to get data into the register. [Enter one *1*, then *0*'s to clear register.]

1. Okay, enter the first number on the Scratch Sheet into the shift register. Ⓣ
2. Okay, set up the wires to the second shift register and enter the second number from the Scratch Sheet. Ⓣ
3. Okay, enter the third number into the third shift register. Ⓣ

[Remove all wires.]

B. Now, set up the inputs to Logic Block #1 and determine the truth table for its inputs and output, as shown on the Scratch Sheet. [Give Subject a pencil.] Ⓣ

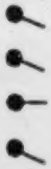
	output
	0
Correct	1
Answer	1
	0

C. I will set up this circuit so that the two shift registers input into the logic block and the logic block outputs to the third shift register. You will have up to 8 minutes to explore this circuit. [Connect--Enter *0*'s to clear all registers.] Now, don't forget the truth table you have just determined for the logic block. Go ahead and manipulate this circuit. Ⓣ

[Everything should be cleared at this point.]

D. Now I am going to introduce a fault into the circuit. Find it as quickly as you can and describe it to me.

[Change Switches

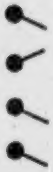


Ⓣ]

[In Shift Register #3, the output of FF #4 remains HIGH.]

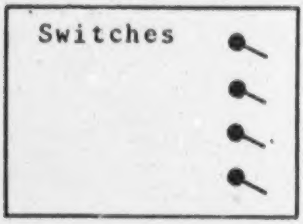
E. I will fix that fault and introduce a new one; fine it and describe it to me.

[Change Switches



Ⓣ]

[Faulty output of Gate 1 in the logic block--OUTPUT REMAINS LOW may be interpreted as faulty input of Gate 3 pulling output of Gate 1 LOW.]



MULTIPLEXER PROBLEMS

A. The shift register in this circuit has a switch on the input so that you can enter information while the switch is in the down position and then circulate the information by putting the switch in the up position. Set up the *Clock* and *Data* Input wires to get a single *1* to circulate in this Ring Counter. Ⓣ

[Be sure switch is in down position before Subject starts.]

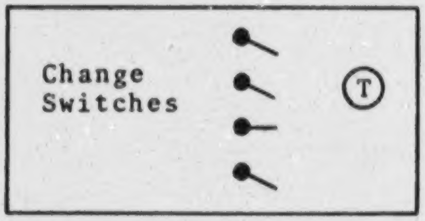
B. Now clear the Ring Counter, disconnect all the wires, and lay them on the table. Ⓣ

C. Now set up 4 data input wires so that you can enter information into the *upper* inputs of the 4 AND Gates. Set the inputs to *1011* from top to bottom as on your scratch sheet and verify it with the probe. Do not use the Ring Counter at all for this exercise. Ⓣ

D. Now get a single *1* circulating in the Ring Counter again. Observe the output of Logic Block #2 as you clock the *1* around the Ring Counter. Explore the circuit with the probe for a few minutes so that you understand it. Ⓣ

[Have *1011* in data input and a *1* in Ring Counter at beginning of next test.]

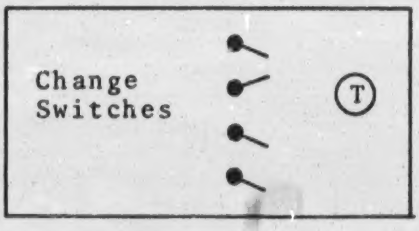
E. I will now introduce a fault in the circuit. Find it and describe it to me.



[Faulty output of Gate 1 in Logic Block #1--OUTPUT REMAINS HIGH--may be interpreted as input from Gate 1 of LOGIC BLOCK #2 pulling output of Gate 1 high.]

[Have *1011* in data input and a *1* in Ring Counter at beginning of next test.]

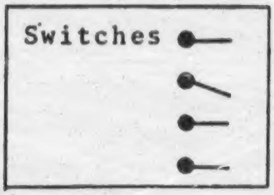
F. I will fix the first fault and introduce another. Find it and describe it to me.



[Faulty input of Gate 3 in Logic Block #2-- INPUT REMAINS LOW.]

Okay, you're finished. Thank you for your participation. Please don't discuss this test with anyone else. We'll be seeing you in a few weeks again.

FORM B: LONG-TERM SKILL TEST



SUPER LOGIC PROBLEMS

A. Connect two input wires to Logic Block #1. There is one fault in this circuit. Find it; tell me the name and number of the faulty component; and describe in your own words what the problem is. Ⓣ

> Lower input in Gate 4 remains HIGH so that all it takes is a high at the upper input to cause a high output. Should require 2 high inputs to make output of this AND Gate high.

B. Disconnect Logic Block #1 and connect the inputs to Logic Block #2. The problem this time is for you to determine if Logic Block #2 is working properly. When you have reached a decision tell me "Yes, it's working properly," or "No, it's not working properly." Ⓣ

> YES, it is working properly.

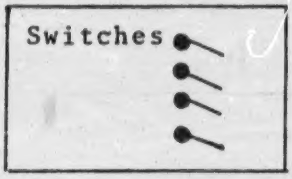
C. Disconnect Logic Block #2 and connect Logic Block #3. There is one fault in this circuit. Find it; tell me the name and number of the faulty component and describe the problem. Ⓣ

> Output of Gate 3 remains high for all input conditions. This AND Gate should require 2 high inputs for a high output.

D. Disconnect Logic Block #3 and connect Logic Block #4. There is one fault in this circuit. Find it; tell me its name and number; and describe the problem. Ⓣ

> Upper input in Gate 4 remains HIGH so that all it takes is a high at the lower input to cause a low output. Should require 2 high inputs to make the output of this NAND Gate low.

FORM B: LONG-TERM SKILL TEST



HALF ADDER PROBLEMS
(Clear All Shift Registers)

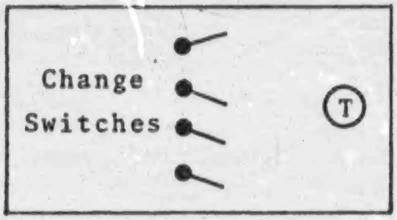
A.

1. Connect an Input wire and a Clock wire to Shift Register #1. Enter the first number on this scratch sheet (hand S scratch sheet). The number is 0001. Ⓣ

2. Enter the second number in Shift Register #2. The number is 1001. Ⓣ

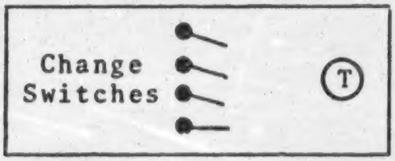
3. Enter the third number in Shift Register #3. The number is 1011. Ⓣ

B. I'll connect up the entire circuit now (connect and clear all registers). Now I am going to introduce a fault into the circuit. Find it; tell me the name and number of the faulty component; and describe in your own words what the problem is.



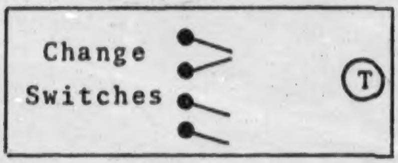
Output of Flip-flop 3 in Shift Register #2 remains LOW; this also means it won't pass a 1 on to Flip-flop 4.

C. I'll fix that fault and introduce a new one. Find it; tell me its name and number; and describe the problem (Clear All Shift Registers).



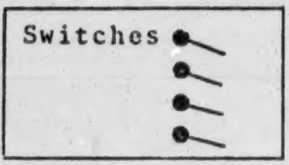
Output of Flip-flop 2 in Shift Register #1 remains HIGH; this also means it keeps passing 1's on to the rest of the shift register and it can't be cleared.

D. I'll fix that fault and introduce a new one. Find it; tell me its name and number; and describe the problem (Clear All Shift Registers).



Output of Gate 1 in the Logic Block remains LOW. This OR Gate should have a high output if either input is high.

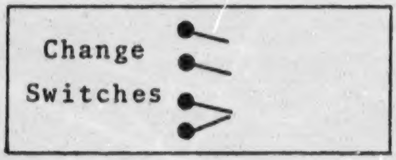
FORM B: LONG-TERM SKILL TEST



MULTIPLEXER PROBLEMS
(Clear Ring Counter)

A. Data can be entered into the Ring Counter when the switch is in the down position; and data can be circulated when the switch is up (leave switch down). Set up the Ring Counter to circulate a single 1. Ⓣ

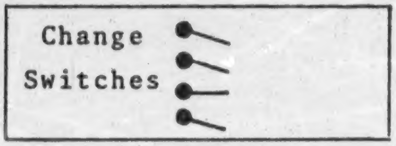
B. I'll set the data inputs to the 4 AND Gates to 1010 (set up; and get 1 into first position in Ring Counter); and I'll introduce a fault into the circuit.



When you are looking for the fault, you may enter new data into the AND Gates or Ring Counter if you want to. Find the fault; tell me its name and number; and describe the problem. Ⓣ

Flip-flop 3 in the Ring Counter remains LOW; it won't pass the one on to Flip-flop 4.

C. I'll fix that fault and introduce a new one. First, I'll set the data inputs to 1011 and get a 1 in the Ring Counter (set data and Ring Counter).



Find the fault; tell me its name and number; and describe the problem. Ⓣ

Output of Gate 1 in Logic Block #1 remains HIGH. This AND Gate should have a high output only when both inputs are high.

D. I'll fix that fault and introduce another; find it; tell me its name and number; and describe the problem.

Change
Switches
T

Output of Gate 3 in Logic Block #2 remains LOW. This OR Gate should have a high output when either input is high.

DISTRIBUTION LIST

Navy:

	Copies
Dr. Marshall J. Farr, Director Personnel and Training Research Programs Office of Naval Research (Code 458) Arlington, VA 22217	4
ONR Branch Office 495 Summer Street Boston, MA 02210 ATTN: Research Psychologist	1
ONR Branch Office 1030 East Green Street Pasadena, CA 91101 ATTN: E. E. Gloye	1
ONR Branch Office 536 South Clark Street Chicago, IL 60605 ATTN: M. A. Bertin	1
Director Naval Research Laboratory Code 2627 Washington, DC 20390	6
Defense Documentation Center Cameron Station, Building 5 5010 Duke Street Alexandria, VA 22314	12
Special Assistant for Manpower OASN (M&RA) Pentagon, Room 4E794 Washington, DC 20350	1
LCDR Charles J. Theisen, Jr., MSC, USN 4024 Naval Air Development Center Warminster, PA 18974	1
Chief of Naval Reserve Code 3055 New Orleans, LA 70146	1

DISTRIBUTION LIST

	Copies
Dr. Harold R. Booher Naval Air Systems Command NAVAIR 04A4 Washington, DC 20361	1
Dr. Lee Miller Naval Air Systems Command AIR-413E Washington, DC 20361	1
CAPT John F. Riley, USN Commanding Officer U.S. Naval Amphibious School Coronado, CA 92155	1
CAPT Ouida C. Upchurch, USN Program Coordinator Bureau of Medicine and Surgery (Code 71G) Washington, DC 20372	1
Chief Bureau of Medicine and Surgery Research Division (Code 713) Washington, DC 20372	1
Chairman Behavioral Science Department Naval Command and Management Division U.S. Naval Academy Luce Hall Annapolis, MD 21402	1
Chief of Naval Education and Training Naval Air Station Pensacola, FL 32508 ATTN: CAPT Bruce Stone, USN	1
Mr. Arnold Rubinstein Naval Material Command (NAVMAT 03424) Room 820, Crystal Plaza #6 Washington, DC 20360	1
Commanding Officer Naval Medical Neuropsychiatric Research Unit San Diego, CA 92152	1

DISTRIBUTION LIST

Copies

Department of the Navy
Office of Civilian Manpower Management
Code 263
Washington, DC 20390 1

Superintendent
Naval Postgraduate School
Monterey, CA 93940
ATTN: Library (Code 2124) 1

Commander, Navy Recruiting Command
4015 Wilson Boulevard
Arlington, VA 22203
ATTN: Code 015 1

Mr. George N. Graine
Naval Ship Systems Command
SHIPS 047C12
Washington, DC 20362 1

Chief of Naval Technical Training
Naval Air Station Memphis (75)
Millington, TN 38054
ATTN: Dr. Norman J. Kerr 1

Commanding Officer, Service School Command
U.S. Naval Training Center
San Diego, CA 92133
ATTN: Code 3030 1

Dr. William L. Maloy
Principal Civilian Advisor for Education
and Training
Naval Training Command, Code 01A
Pensacola, FL 32508 1

Dr. Alfred F. Smode, Staff Consultant
Training Analysis and Evaluation Group
Naval Training Equipment Center
Code N-OOT
Orlando, FL 32813 1

Dr. Hanns H. Wolff
Technical Director (Code N-2)
Naval Training Equipment Center
Orlando, FL 32813 1

DISTRIBUTION LIST

	Copies
Chief of Naval Training Support Code N-21 Building 45 Naval Air Station Pensacola, FL 32508	1
Dr. Robert French Naval Undersea Center San Diego, CA 92132	1
CDR Richard L. Martin, USN Fighter Squadron 124 NAS Miramar, CA 92145	1
Dr. John Ford, Jr. Navy Personnel R&D Center San Diego, CA 92152	1
Navy Personnel R&D Center San Diego, CA 92152 ATTN: Code 10	5

Army:

Headquarters U.S. Army Administration Center Personnel Administration Combat Development Activity ATCP-HRO Ft. Benjamin Harrison, IN 46249	1
Armed Forces Staff College Norfolk, VA 23511 ATTN: Library	1
Director of Research U.S. Army Armor Human Research Unit Building 2422 Morade Street Fort Knox, KY 40121 ATTN: Library	1
Commandant United States Army Infantry School ATTN: ATSH-DET Fort Benning, GA 31905	1

DISTRIBUTION LIST

	Copies
Deputy Commander U.S. Army Institute of Administration Fort Benjamin Harrison, IN 46216 ATTN: EA	1
Dr. Frank J. Harris U.S. Army Research Institute 1300 Wilson Boulevard Arlington, VA 22209	1
Dr. Ralph Dusek U.S. Army Research Institute 1300 Wilson Boulevard Arlington, VA 22209	1
Mr. Edmund F. Fuchs U.S. Army Research Institute 1300 Wilson Boulevard Arlington, VA 22209	1
Dr. Leon H. Nawrocki U.S. Army Research Institute 1300 Wilson Boulevard Arlington, VA 22209	1
Dr. J. E. Uhlaner, Technical Director U.S. Army Research Institute 1300 Wilson Boulevard Arlington, VA 22209	1
Dr. Joseph Ward U. S. Army Research Institute 1300 Wilson Boulevard Arlington, VA 22209	1
HQ USAREUR & 7th Army ODCSOPS USAREUR Director of GED APO New York, NY 09403	1
Air Force:	
Research Branch (AF/DPXYR) Pentagon, Room 5C428 Washington, DC 20330	1

DISTRIBUTION LIST

	Copies
Dr. G. A. Eckstrand (AFHRL/AS) Wright-Patterson AFB, OH 45433	1
Dr. Ross L. Morgan (AFHRL/AST) Wright-Patterson AFB, OH 45433	1
AFHRL/DOJN Stop #63 Lackland AFB, TX 78236	1
Dr. Martin Rockway (AFHRL/TT) Lowry AFB, CO 80230	1
Major P. J. DeLeo Instructional Technology Branch AF Human Resources Laboratory Lowry AFB, CO 80230	1
AFOSR/NL 1400 Wilson Boulevard Arlington, VA 22209	1
Commandant USAF School of Aerospace Medicine Aeromedical Library (SUL-4) Brooks AFB, TX 78235	1
Dr. Sylvia R. Mayer (MCIT) Headquarters Electronic Systems Division LG Hanscom Field Bedford, MA 01730	1
CAPT Jack Thorpe, USAF Flying Training Division (HRL) Williams AFB, AZ 85224	1
Marine Corps:	
Mr. E. A. Dover Manpower Measurement Unit (Code MPI) Arlington Annex, Room 2413 Arlington, VA 20380	1
Commandant of the Marine Corps Headquarters, U.S. Marine Corps Code MPI-20 Washington, DC 20380	1

DISTRIBUTION LIST

Copies

Director, Office of Manpower Utilization
Headquarters, Marine Corps (Code MPU)
MCB (Building 2009)
Quantico, VA 22134 1

Dr. A. L. Slafkosky
Scientific Advisor (Code RD-1)
Headquarters, U.S. Marine Corps
Washington, DC 20380 1

Coast Guard:

Mr. Joseph J. Cowan, Chief
Psychological Research Branch (G-P-1/62)
U.S. Coast Guard Headquarters
Washington, DC 20590 1

Other DOD:

Lt. Col. Henry L. Taylor, USAF
Military Assistant for Human Resources
OAD (E&LS) ODDR&E
Pentagon, Room 3D129
Washington, DC 20301 1

Mr. William J. Stormer
DOD Computer Institute
Washington Navy Yard, Building 175
Washington, DC 20374 1

Col. Austin W. Kibler
Advanced Research Projects Agency
Human Resources Research Office
1400 Wilson Boulevard
Arlington, VA 22209 1

Mr. Thomas C. O'Sullivan
Advanced Research Projects Agency
Human Resources Research Office
1400 Wilson Boulevard
Arlington, VA 22209 1

DISTRIBUTION LIST

Copies

Helga L. Yeich
Advanced Research Projects Agency
Manpower Management Office
1400 Wilson Boulevard
Arlington, VA 22209 1

Other Government:

Dr. Eric McWilliams, Program Manager
Technology and Systems, TIE
National Science Foundation
Washington, DC 20550 1

Dr. Andrew R. Molnar
Technological Innovations in Education
National Science Foundation
Washington, DC 20550 1

Miscellaneous:

Dr. Scarvia B. Anderson
Educational Testing Service
17 Executive Park Drive, N.E.
Atlanta, GA 30329 1

Dr. John Annett
The Open University
Milton Keynes
Buckinghamshire
ENGLAND 1

Dr. Richard C. Atkinson
Stanford University
Department of Psychology
Stanford, CA 94305 1

Dr. Gerald V. Barrett
University of Akron
Department of Psychology
Akron, OH 44325 1

Dr. Bernard M. Bass
University of Rochester
Management Research Center
Rochester, NY 14627 1

DISTRIBUTION LIST

Copies

Dr. David G. Bowers
University of Michigan
Institute for Social Research
Ann Arbor, MI 48106 1

Mr. Kenneth M. Bromberg
Manager - Washington Operations
Information Concepts, Inc.
1701 North Fort Myer Drive
Arlington, VA 22209 1

Dr. Ronald P. Carver
American Institutes for Research
Foxhall Square
3301 New Mexico Avenue, N.W.
Washington, DC 20016 1

Centry Research Corporation
4113 Lee Highway
Arlington, VA 22207 1

Dr. Allan M. Collins
Bolt Beranek and Newman, Inc.
50 Moulton Street
Cambridge, MA 02138 1

Dr. Rene' V. Dawis
University of Minnesota
Department of Psychology
Minneapolis, MN 55455 1

ERIC
Processing and Reference Facility
4833 Rugby Avenue
Bethesda, MD 20014 1

Dr. Victor Fields
Montgomery College
Department of Psychology
Rockville, MD 20850 1

Dr. Edwin A. Fleishman
American Institutes for Research
Foxhall Square
3301 New Mexico Avenue, N.W.
Washington, DC 20016 1

DISTRIBUTION LIST

Copies

Dr. Dexter Fletcher
University of Illinois
at Chicago Circle
Department of Psychology
Chicago, IL 60680 1

Dr. Robert Glaser, Director
University of Pittsburgh
Learning Research and Development Center
Pittsburgh, PA 15213 1

Dr. Henry J. Hamburger
University of California
School of Social Sciences
Irvine, CA 92664 1

HumRRO
Division No. 3
P.O. Box 5787
Presidio of Monterey, CA 93940 1

HumRRO
Division No. 4, Infantry
P.O. Box 2086
Fort Benning, GA 31905 1

HumRRO
Division No. 5, Air Defense
P.O. Box 6057
Fort Bliss, TX 79906 1

HumRRO
Division No. 6, Library
P.O. Box 428
Fort Rucker, AL 36360 1

Dr. Lawrence B. Johnson
Lawrence Johnson and Associates, Inc.
200 S. Street, N.W., Suite 502
Washington, DC 20009 1

Dr. Milton S. Katz
MITRE Corporation
Westgate Research Center
McLean, VA 22101 1

DISTRIBUTION LIST

	Copies
Dr. Steven W. Keele University of Oregon Department of Psychology Eugene, OR 97403	1
Dr. David Klahr Carnegie-Mellon University Department of Psychology Pittsburgh, PA 15213	1
Dr. Alma E. Lantz University of Denver Denver Research Institute Industrial Economics Division Denver, CO 80210	1
Dr. Donald A. Norman University of California, San Diego Center for Human Information Processing LaJolla, CA 92037	1
Mr. A. J. Pesch, President Eclectech Associates, Inc. P.O. Box 178 North Stonington, CT 06359	1
Mr. Luigi Petrullo 2431 North Edgewood Street Arlington, VA 22207	1
Dr. Joseph W. Rigney University of Southern California Behavioral Technology Laboratories 3717 South Grand Los Angeles, CA 90007	1
Dr. Leonard L. Rosenbaum, Chairman Montgomery College Department of Psychology Rockville, MD 20850	1
Dr. George E. Rowland Rowland and Company, Inc. P.O. Box 61 Haddonfield, NJ 08033	1

DISTRIBUTION LIST

	Copies
Dr. Arthur I. Siegel Applied Psychological Services 404 East Lancaster Avenue Wayne, PA 19087	1
Dr. C. Harold Stone 1428 Virginia Avenue Glendale, CA 91202	1
Mr. Dennis J. Sullivan 725 Benson Way Thousand Oaks, CA 91360	1
Dr. Benton J. Underwood Northwestern University Department of Psychology Evanston, IL 60201	1
Dr. David J. Weiss University of Minnesota Department of Psychology Minneapolis, MN 55455	1
Dr. Anita West Denver Research Institute University of Denver Denver, CO 80210	1
Dr. Kenneth N. Wexler University of California School of Social Sciences Irvine, CA 92664	1